JACIE Agency report - NASA

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NASA/GSFC

Overview

Research and operational systems for earth science

- Range of spatial resolutions
- Multi-agency, international collaborations
- Continued development and launch of: SAGE-III/ISS, ECOSTRESS/ISS, GEDI/ISS, CYGNSS, TEMPO, GRACE-FO, ICESat-2, SWOT, NISAR, PACE
  - OCO-3 completion and flight to ISS in late 2017
  - CLARREO Pathfinder on ISS – official start imminent
- Second decadal survey is now underway by the National Research Council
- Sustainable Land Imaging Program (w/USGS; NASA funds flight hardware)


Formulation
Implementation
Primary Ops
Extended Ops
Sentinel-6A/B
Earth Science Instruments on ISS:
RapidScat, CATS,
LIS, SAGE III (on ISS), TSIS-1, OCO-3,
ECOSTRESS,
GEDI, CLARREO-PF
Landsat 9
PACE
NI-SAR
SWOT
TEMPO
JPSS-2 (NOAA)
RBI, OMPS-Limb
GRACE-FO (2)
ICESat-2
CYGNSS
ISS
SORCE,
TCTE (NOAA)
NISTAR, EPIC
(NOAA'S DSCOVR)
QuikSCAT
EO-1
Landsat 7
(USGS)
Terra
SMAP
Suomi NPP
(NOAA)
Aqua
CloudSat
Landsat 8
(USGS)
CALIPSO
GPM
Aura
GRACE (2)
OSTM/Jason 2
(NOAA)
OCO-2

NASA ESD Flight Portfolio 2013 - 2022

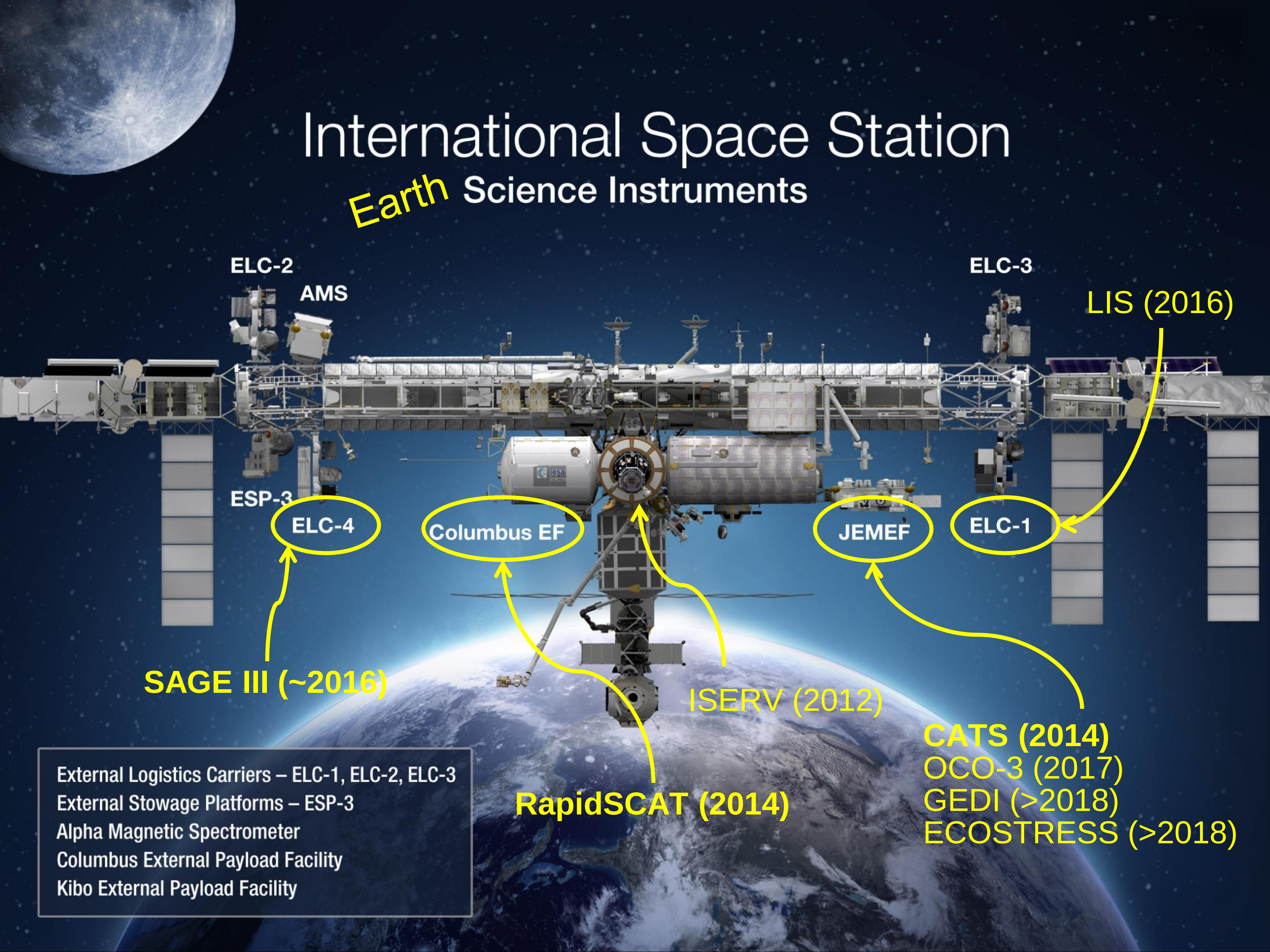
- The Earth Systematic Missions (ESM) ***development*** missions in this period include:
  - ICESat-2, SAGE III, GRACE-FO, SWOT, Landsat-9, RBI, TSIS-1 and -2, OMPS-Limb, NISAR, PACE, Jason CS/Sentinel 6A and -B, CLARREO Pathfinder

- The Earth Systematic Missions (ESM) ***on-orbit**** missions include:
  - SMAP (>2021), DSCOVR (2019), S-NPP (>2021), GPM (>2021), LDCM (>2021), Terra (>2021), Aqua (>2021), Aura (>2021), OSTM (>2021), QuikScat (2015), SORCE (2017), and EO-1 (2016); also RapidScat (2017) and CATS (>2016)

- The Earth System Science Pathfinder (ESSP) ***development*** missions in this period include:
  - OCO-3, CYGNSS, TEMPO, GEDI, ECOSTRESS, EVS-2 and -3 and Venture Technology selections (GrAOWL, Tempest), EVM-2 & 3, EVI-3, 4, 5, and 6

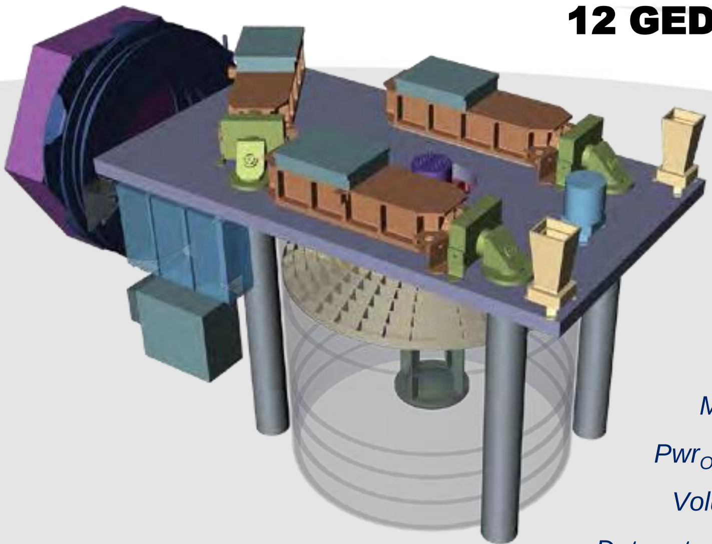
- The Earth System Science Pathfinder (ESSP) ***on-orbit*** missions include:
  - OCO-2 (>2021), GRACE (2018), CALIPSO (>2021), CloudSat (2018), Aquarius (>2021)

**On-orbit dates correspond to end-of-mission assumptions, consistent with 2015 Sr. Review*


International Space Station
Earth Science Instruments
ELC-2
AMS
ELC-3
LIS (2016)
ESP-3
ELC-4
Columbus EF
JEMEF
ELC-1
SAGE III (~2016)
ISERV (2012)
RapidSCAT (2014)
CATS (2014)
OCO-3 (2017)
GEDI (>2018)
ECOSTRESS (>2018)
External Logistics Carriers – ELC-1, ELC-2, ELC-3
External Stowage Platforms – ESP-3
Alpha Magnetic Spectrometer
Columbus External Payload Facility
Kibo External Payload Facility

Venture Class Activities - GEDI

12 GEDI Lidar: Global Ecosystem Dynamics Investigation Lidar
PI: Ralph Dubayah



Mass = 230 kg

$Pwr_{Orb\ Avg}$ = 516 W

Volume = .xx m^3

Data $rate_{avg}$ = 2.1 Mbps

Mission:

GEDI will characterize the effects of changing climate and land use on ecosystem structure and dynamics, enabling improved understanding of Earth's carbon cycle and biodiversity. GEDI will provide the first global, high-resolution observations of forest vertical structure.

Goals:

GEDI will address the following questions:
- What is the above-ground carbon balance of the land surface?
- What role will land surface play in mitigating atmospheric CO2?
- How does ecosystem structure affect habitat quality and biodiversity?

GEDI measurements will quantify the following:
- Distribution of above-ground carbon at fine spatial resolution
- Changes in carbon resulting from disturbance and subsequent recovery
- Spatial and temporal distribution of forest structure and its relationship to habitat quality and biodiversity
- Sequestration potential of forests over time w/changing land use, climate

Instrument: Lidar

Mission & Science Team:

Principal Investigator: Ralph Dubayah, UMD
Project Manager: TBD, GSFC
Instrument System Engineer: Cheryl Salerno, GSFC
Deputy PI Instrument / Instrument Scientist: Bryan Blair, GSFC
Deputy PI Science: Scott Goetz, WHRC
Instrument Deputy Project Manager: Thomas Johnson, GSFC

Mission & Science Team:

University of Maryland, College Park
Goddard Space Flight Center
Woods Hole Research Center
US Forest Service
Brown University

Instrument Details:

- Self-contained laser altimeter
  - 3 lasers are split into 7 beams dithered to produce 14 ground track spot beams.
  - Beams have a 25 meter footprint and are spaced 500 m cross-track and 60 m along-track to produce fine grids of forest structure.
- 70 cm diameter telescope/receiver.
  - Detector has 75% transmission and 50% quantum efficiency.
  - Si:APD detectors: Near-photon-noise limited, >500:1 dynamic range
  - IFOV matched to contain return spot beams
- GPS, IMU, Star Trackers give precise ranging, attitude and position.
- A single-axis mechanism rotates the instrument about the roll axis, providing off-nadir pointing for global coverage.
- Canopy profile accurate to 1 m
- Geolocation < 10 m for plot calibration
- Biomass error < 20% at pixel level

FY16 Cost: $94.034M, $18.652M reserve, $2.815 contribution

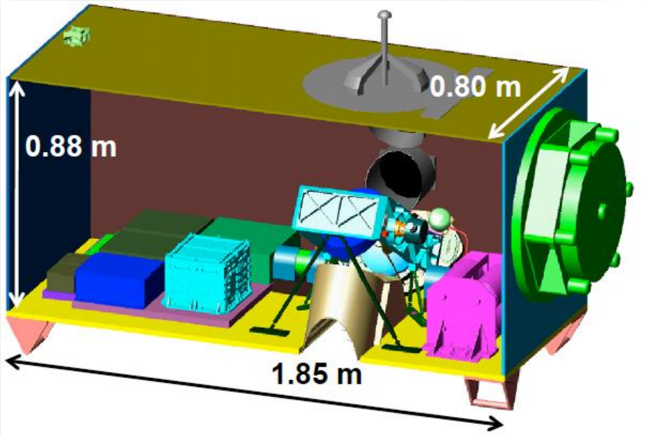
Descopes: Reduce lasers from 3 to 2, elim. dithering unit.: $11.4M (FY16 $)

Threshold: Acquire canopy vertical profile to estimate above-ground woody carbon density for vegetated areas at <1 km.

Venture Class Activities - ECOSTRESS

ECOSTRESS: ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station

PI: Simon Hook



Mass = 266 kg

$Pwr_{Orb\ Avg}$ = 527 W

Volume = 1.30 m^3

Data $Rate_{avg}$ = 2.32 Mbps

Mission:

An Earth Venture Instrument-2 selection, ECOSTRESS will provide the first high spatiotemporal resolution thermal infrared measurements of Earth's surface from ISS. Measurements at varying times over the diurnal cycle will reveal answers related to water stress in plants and how selected regions will respond to future climate changes.

Goals:

- Identify critical thresholds of water use and water stress in key climate-sensitive biomes.
- Detect the timing, location, and predictive factors leading to plant water uptake decline and/or cessation over the diurnal cycle
- Measure agricultural water consumptive use over the contiguous United States (CONUS) at spatiotemporal scales applicable to improve drought estimation accuracy

Mission & Science Lead:

Principal Investigator: Simon Hook, JPL

Major Partners:

Jet Propulsion Laboratory

Instrument Details:

- Thermal infrared radiometer
- Cross-track whisk broom scanner
- Swath width: 384 km (51°)
- Spatial resolution: 38 m x 57 m (nadir) pixels
- Five thermal IR bands between 8.3 and 12.1 microns
- Noise equivalent delta temperature: ≤ 0.1 K
- Two COTS cryocoolers for 60 K focal plane
- Typical revisit of 90% of CONUS every 4 days at varying times over diurnal cycle

Heritage:

Prototype Hyperspectral Infrared Imager (HyspIRI) Thermal Infrared Radiometer (PHyTIR; a laboratory instrument); Algorithms: ASTER, MODIS, Landsat

CLARREO Pathfinder

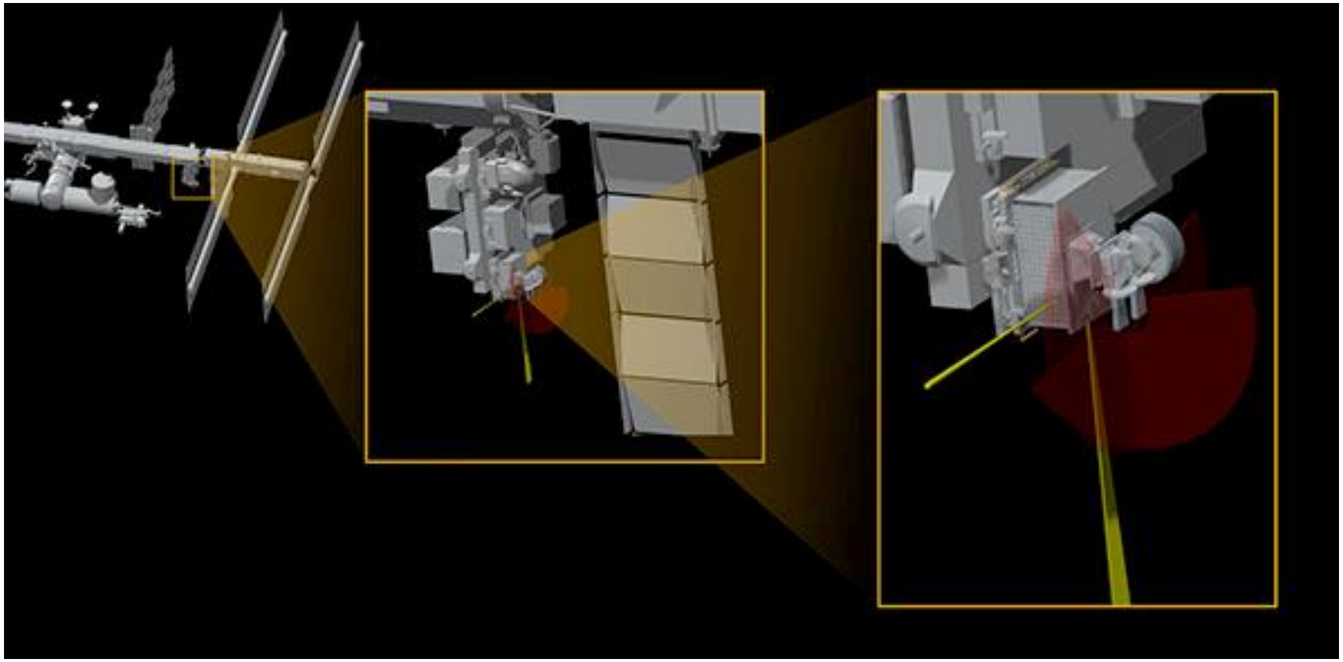
Pathfinder provides an equal array of challenges and opportunities

- Just received its formal authority to proceed
- Many difficult decisions still remain on how best to meet schedule and cost
- Lessons learned from implementing the Pathfinder will be invaluable to future CLARREO missions as well as other earth science missions
  - Laboratory calibration approaches
  - On orbit operations and improved calibration
  - Challenges of high-accuracy intercalibration
- Reduce risk and provide confidence that full CLARREO could achieve the science goals
- Identify possible design modifications for full mission

CLARREO Pathfinder

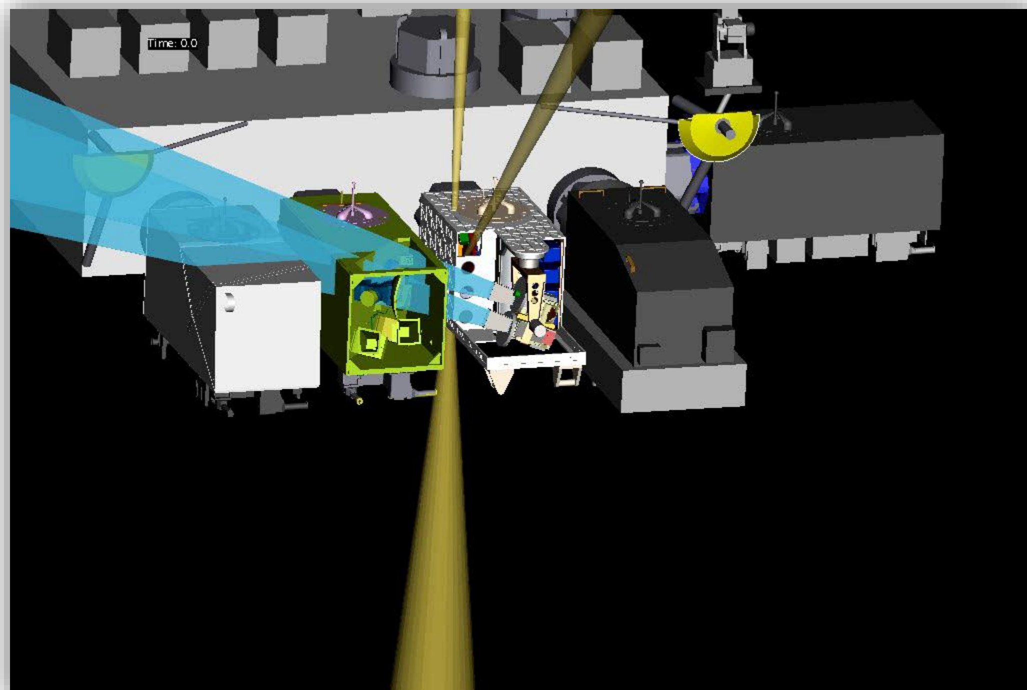
Hosted on International Space Station (ISS) in 2020 time frame

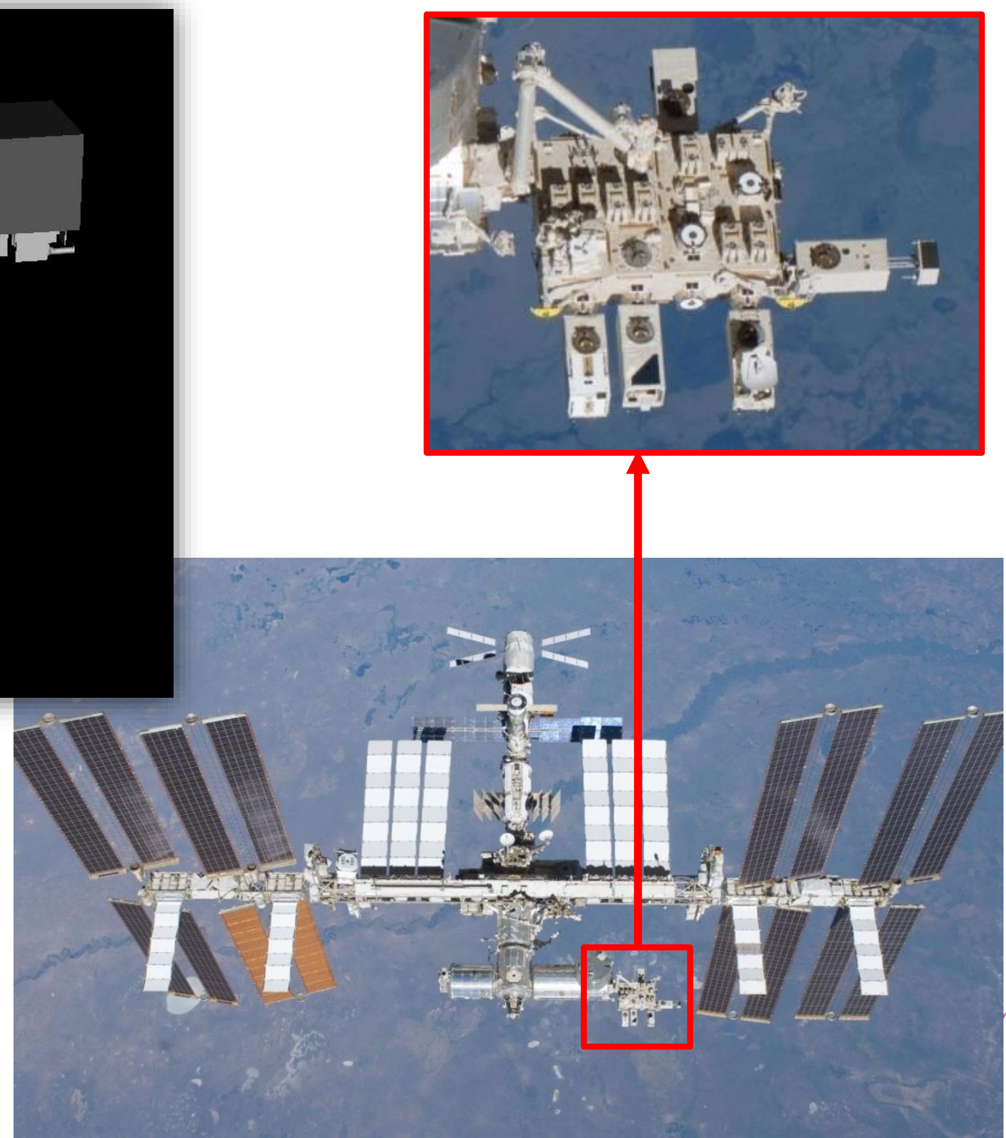
- Slotted on the ExPRESS logistics carrier (ELC-1)
- Studies underway to determine if funds can support flight of two instruments, a Reflected Solar (RS) and an Infrared (IR) spectrometer



CLARREO Pathfinder

ISS Tech Demo studies showed ISS is feasible from mass, power, data rate and volume

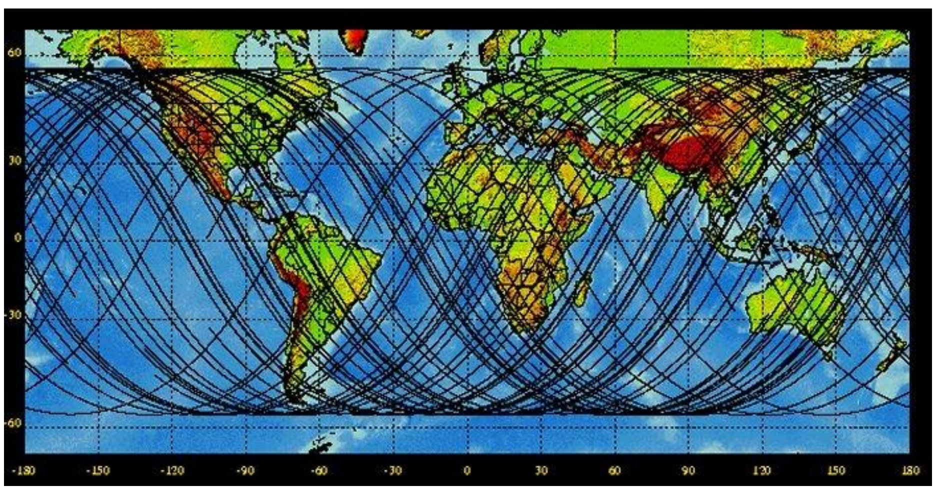




Previous ISS studies showed how operations could take place

Pathfinder limitations

Pathfinder is **not** CLARREO due to budget and orbital limitations

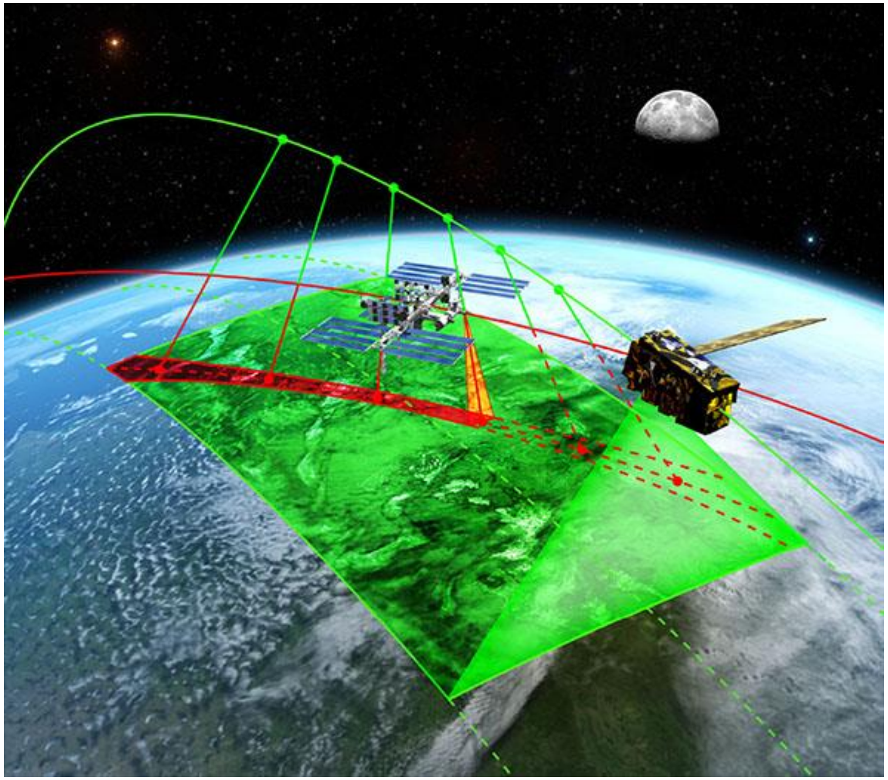


- Accuracy trades to maintain cost and schedule
- Cannot achieve direct climate benchmark
  - ISS orbit is not global
  - Limited Class D lifetime < 5 year requirement
  - ISS orbit conditions limit IR nadir collection to about 75% of total time on orbit

But still, CLARREO Pathfinder is a great opportunity

Step towards demonstrating measurement technologies for full mission

- Prove first on-orbit SI traceable calibration methodologies to achieve accuracies 5x to 10x higher than current IR and RS instruments
- Precessing orbit enhances sampling for inter-calibration of existing sensors
- Put lunar spectral irradiance on an SI traceable scale with 10 to 20 times current accuracy



Sentinel 2/Landsat 8 cross-calibration

Work included prelaunch evaluation of integrating spheres for MSI and OLI (NASA, ESA)

- Analysis of MSI diffuser witness samples (NASA, U. Arizona, ESA)
- Post-S2 launch has concentrated on
  - OLI-MSI Radiometric Comparisons
  - Vicarious calibration using automated U. Arizona RadCaTS system
  - Comparison over PICS sites (USGS, SDSU, NASA)
  - OLI-MSI Geometric/Spatial Comparisons (USGS)
  - Geometric Accuracy Assessment
  - Image Registration Accuracy
  - Band Registration Accuracy
- Significant international joint agency effort
  - Brian Markham (NASA Goddard Space Flight Center)
  - Jim Storey (SGT/USGS) and Ron Morfitt (USGS)
  - Jeff Czapla-Myers (Univ. of Arizona) and Dennis Helder (SDSU)
  - Martin Claverie (UMD)
  - Funding from NASA LCLUC, LcSPO, and USGS

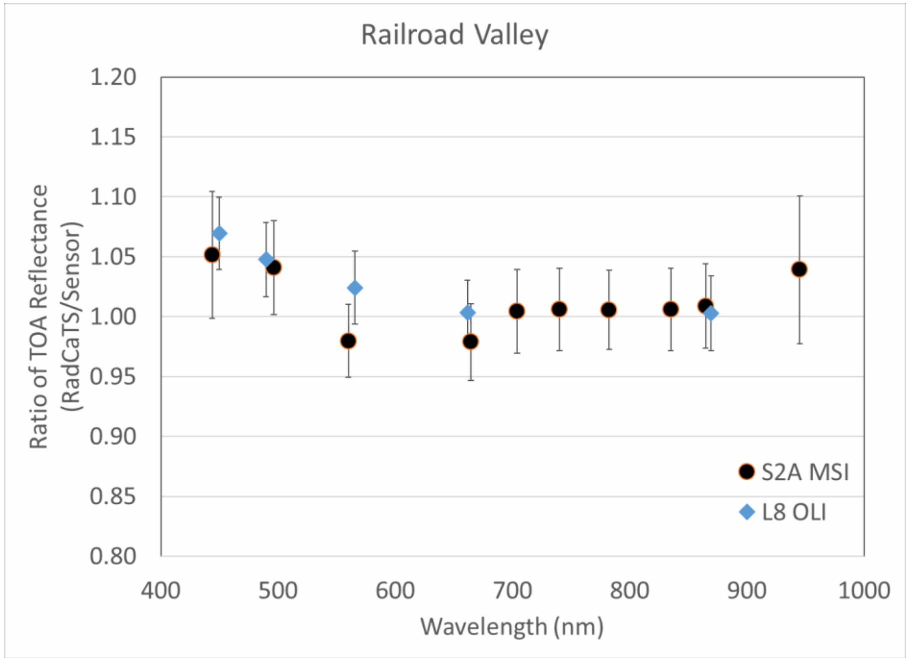
Sentinel 2/Landsat 8 cross-calibration

Initial radiometric results for the Sentinel-2a MSI data are encouraging

- Early radiometric results based on pre-launch gains and do not reflect the on-orbit reflectance based calibration using the diffuser
    - Initial data appear to be at or near requirements
    - MSI gain updates appear to show better agreement with OLI
- Geometric and spatial performance of Sentinel-2 MSI data are within specification
    - Absolute geolocation of MSI L1C products may differ from Landsat-8 L1T products by up to ~37m (2σ), due to errors in the Landsat GLS2000 reference
        - Updates to the Landsat GLS2000 will resolve this by 2017
- Landsat CVT will continue to monitor and update analyses when appropriate

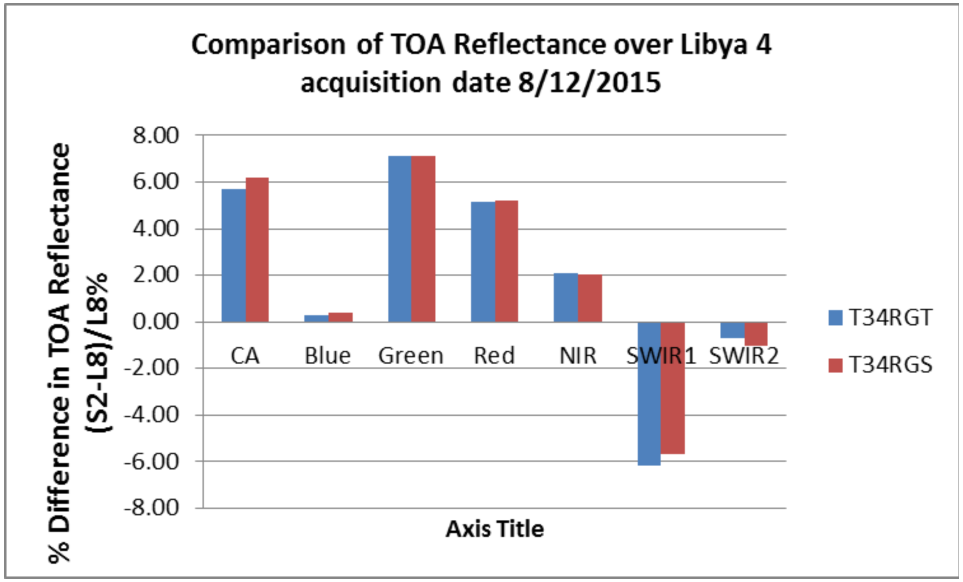
Sentinel 2/Landsat 8

OLI/MSI TOA Reflectance Compared to U. Az RadCaTS Observations



- OLI: Mar 2013 – Nov 2015, 14 dates
- MSI: Aug–Oct 2015, 4 dates (pre-operational gains)

OLI/MSI Difference in TOA Reflectance (Libya 4 PICS)



USGS results. (SDSU results over same scene consistent to within 1% except red band)

Land Imaging Evolution

While recognizing the scientific need for continuity with the 43-year Landsat record, we are seeing new trends & opportunities in land remote sensing

- *Evolving user needs for…*
  - *Improved temporal revisit*
  - *Additional spectral coverage & resolution*
  - *Integration with other modalities (lidar, radar)*
- *Increasing use of "small sat" platforms and distributed architectures*
- *Increasing number of commercial imaging systems*
- *Potential synergy with international systems (e.g. Sentinel-2)*
- *High-performance computing and increased emphasis on information rather than images*

Our challenge is to advance the measurement capability, while preserving continuity and constraining program costs

Sustainable Land Imaging (SLI) in the President's FY17 Budget

A 3-part program for a sustainable and responsible land imaging program through 2035:

1. **Landsat 9** (fully Class-B rebuild of Landsat 8) anticipated to launch in FY 2021
   - Low programmatic risk implementation of a proven system with upgrades to bring the whole system to Class B

2. **Land Imaging Technology and Systems Innovation**
   - Hardware, operations, and data management/processing investments to reduce risk in next generation missions

3. **Landsat 10**, Class B full spectrum, to launch ~2027-2028
   - Mission architecture to be informed by the technology investments (2015-), leading to definition ~2020

SLI: NASA Present Status

Landsat 9 Project initiated with FY15 funds

- Directed to NASA's Goddard Space Flight Center (GSFC)
- Project Office established and substantially staffed
- OLI-2 Instrument and Landsat 9 spacecraft procurement actions in work
- TIRS-2 development in progress
- Launch ASAP, likely NET 12/2020 – there is sufficient funding authority for FY16

Technology studies underway for Landsat 10 definition and long-term technology infusion

- Detector component development
- Overall instrument size reduction using advanced technologies
- ROSES SLI Technology call released (ROSES 2015 A.47 released 23 Dec 2015 with proposals due 30 Mar 2016)

SLI: NASA Present Status

NASA solicited, selected, and initiated science investigations focused on construction of multi-system fusion data sets ("Multi-Source Land Imaging Science")

- "…[W]e solicit for efficient use and seamless combination with Landsat, of satellite sensor data from international Landsat-type moderate resolution (~30 m ground resolution), multispectral sources on continental to global scales. A primary focus is on developing algorithms and prototyping products for combined use of data from Landsat and Sentinel-2 toward global land monitoring. However, we also welcome proposals combining Landsat with other sources of moderate resolution data, such as IRS and/or CBERS…"
- 7 investigations selected, $1.3M/year total, 3-year studies (see later slide)

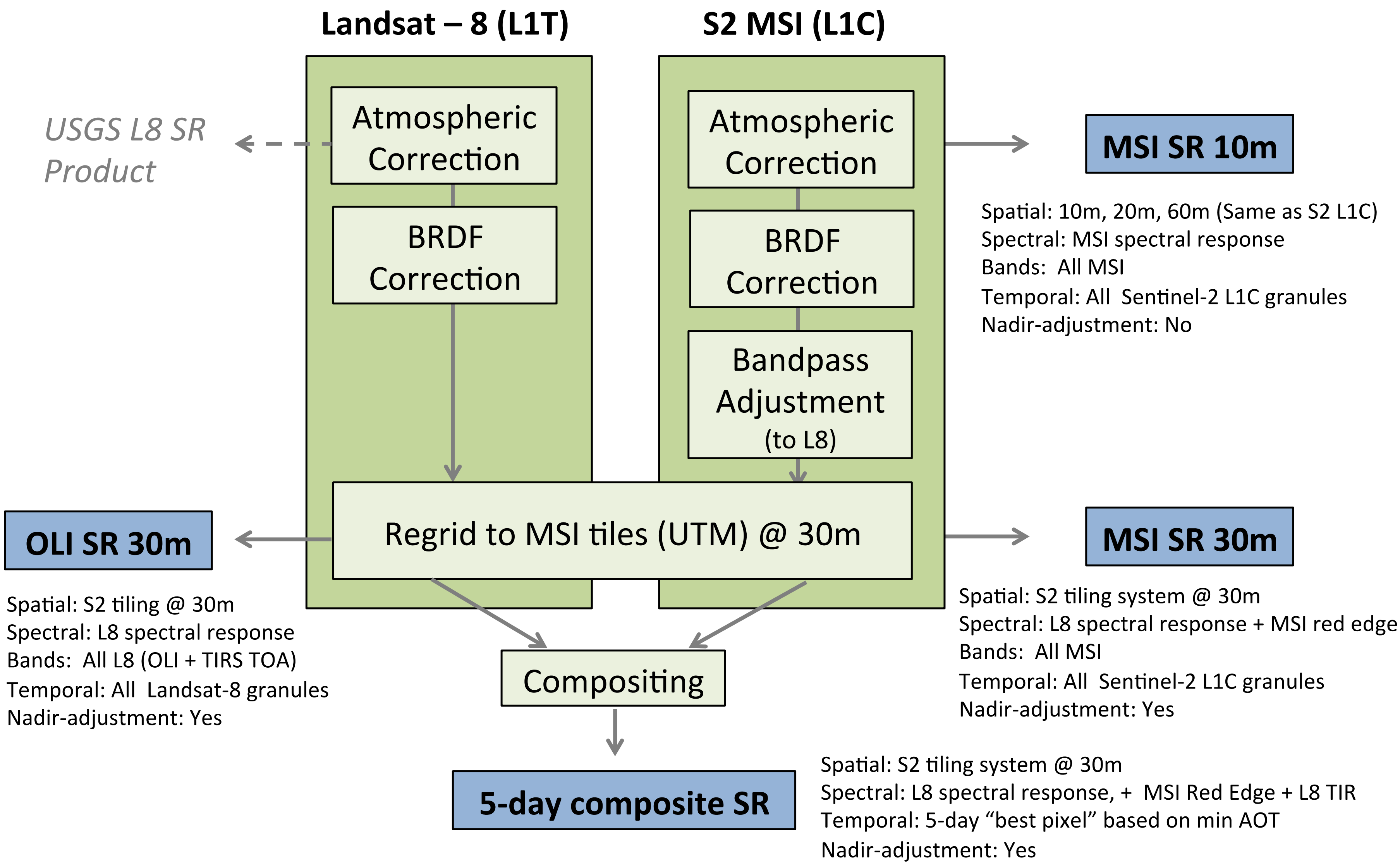
Copernicus data access agreements with EU signed (including all Sentinel-2 data)

NASA Science Activities Relevant to SLI

NASA is investing in synergistic use of international data sources to improve land monitoring

- Multi-Source Land Imaging Science (MuSLI) Team
  - Solicited through the Land Cover / Land Use Change (LCLCU) research program
  - 3-year activity to prototype land products from fusion of international systems, with focus on Sentinel-1,2 and Landsat (see next slide)
  - Coordinated with ESA SEOM (Scientific Exploitation of Operational Mission) Program
- Harmonized Landsat / Sentinel-2 (HLS) Reflectance Products
  - Goal: seamless, near-daily 30m surface reflectance record from Landsat-8 and Sentinel-2a,b
  - Includes common atmospheric correction, spectral & BRDF adjustment, resampling to common grid & frame ("data cube" concept)
  - Collaboration among NASA GSFC, ARC, and UMD
  - Implemented on NASA Earth Exchange (NEX) – initially as a series of test sites.

HLS Processing Flow



NASA Multi-Source Land Imaging Projects

Project Title	PI	International Collaborators
Multisource Imaging of Seasonal Dynamics in Land Surface Phenology	Friedl/Boston U	Eklundh / Lund
Integrating Landsat 7, 8 and Sentinel 2 Data in Improving Crop Type Identification and Area Estimation	Hansen/U. Maryland	Defourny / Louvain
Towards Near Daily Monitoring of Inundated Areas Over North America Through Multi-Source Fusion of Optical and Radar Data	Lang / U. Maryland	Creed / Western
Prototyping a Landsat-8/Sentinel-2 Global Burned Area Product	Roy / SDSU	Chuvieco / Alcala; Tansey / Leicester
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	Hoekman / Wageningen; Le Toan / CESBIO
Multi-Source Imaging of Infrastructure and Urban Growth Using Landsat, Sentinel and SRTM	Small / Columbia U	Esch / DLR
Multi-Source Imaging of Time-Serial Tree and Water Cover at Continental to Global Scales	Townshend / U. Maryland	Schmullius /Jena

Decadal Survey for Earth Sciences

NASA relies on science community to identify and prioritize leading-edge scientific questions and observations to answer them

- A principal means by which NASA engages science community is through the National Research Council (NRC)
- NRC conducts studies that provide a science community consensus on key questions posed by NASA and other U.S. Government agencies
- Broadest of these studies in NASA's areas of research are decadal surveys
  - Look out ten or more years into the future
  - Prioritize research areas, observations, and notional missions to make those observations

2017 Decadal Survey

- Executed contracts from sponsors: hoping for mid-June
  - First task: appointment of survey leadership, to be followed by rest of steering committee. Panel appointments once survey organization finalized.
  - CESAS working on white paper requests to front-end survey
- NRC Boards covering atmospheric sciences, polar research, ocean science, hydrology, and the solid Earth will be collaborating partners with the Space Studies Board
- Survey Leads: Waleed Abdalati (CU) and Tony Busalacchi (UMD)
- Final report due ~ July 2017

Decadal Survey 2017

- Assess progress in addressing major scientific and application challenges outlined in 2007 Earth Science Decadal Survey
- Develop prioritized list of top-level science and application objectives to guide space-based Earth observations over 10-year period commencing approximately at the start of fiscal year 2018
- Identify gaps and opportunities in programs of record at NASA, NOAA, and USGS in pursuit of top-level science and application challenges—including space-based opportunities providing sustained and experimental observations

2017 Decadal Survey

- Recommend approaches to facilitate development of robust, resilient, and balanced U.S. program of Earth observations
  - Science priorities
  - Implementation costs
  - New technologies and platforms
  - Interagency partnerships
  - International partners
  - In situ and other complementary programs carried out at NSF, DoE, DoA, DoD

Summary

2017 Decadal Survey will play a key role in the emphasis of NASA's Earth Observations

- Numerous missions with relevance to JACIE
- Data harmonization is a dominant topic
  - SLI/Landsat/Sentinel
  - CLARREO Pathfinder
- Role for sub-orbital missions
  - Technology demonstration
  - Improved science
- New technologies for answering new questions