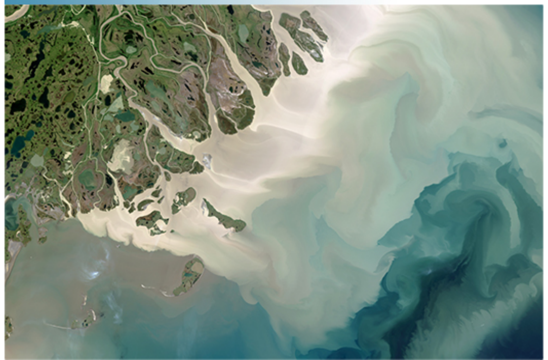
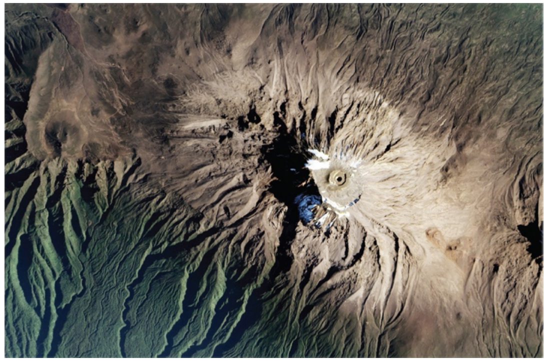
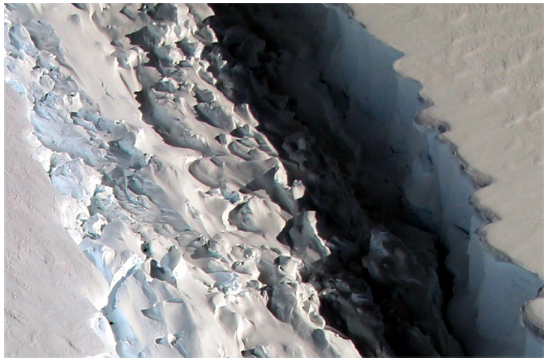
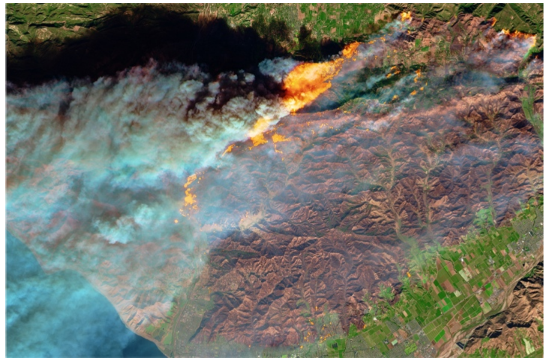
SCIENCE

NASA Status Update
LSI-VC-6

David B. Jarrett

Jeffrey G. Masek

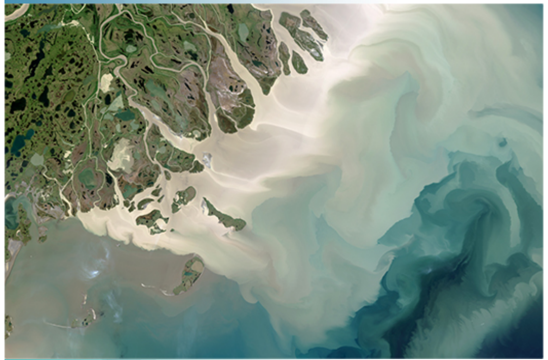
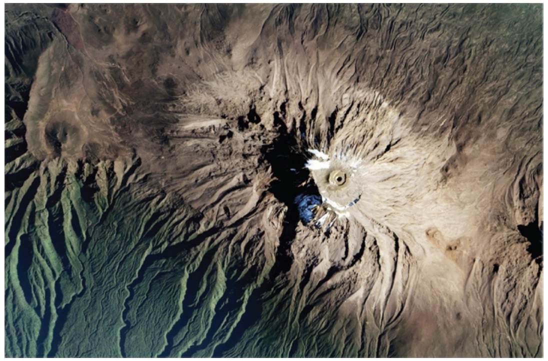
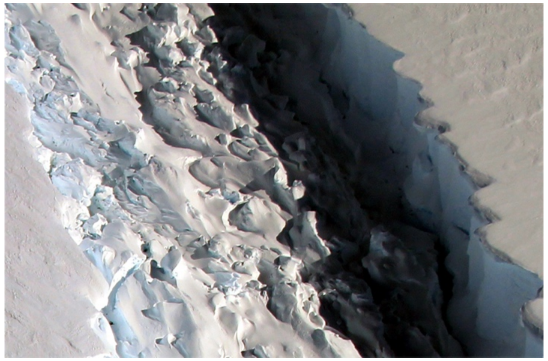
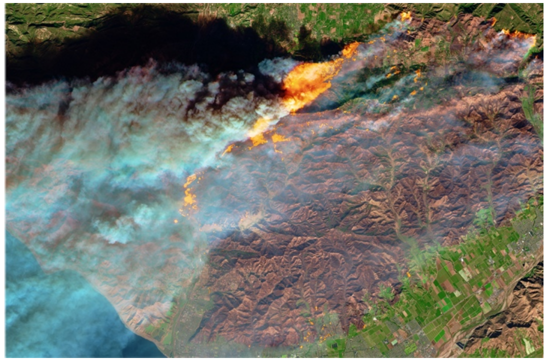
NASA Earth Science

6 September 2018

Agenda

• NISAR & Landsat 9 Status	Jeff Masek
• NASA Earth Science 2017 Decadal Survey Planning	Dave Jarrett

SCIENCE

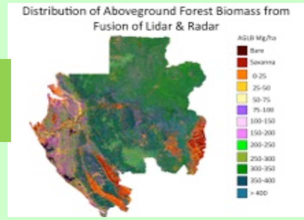
NISAR & Landsat 9 Status

Jeffrey G. Masek
Landsat 9 Project Scientist
NASA Goddard Space Flight Center

NISAR Key Scientific Objectives

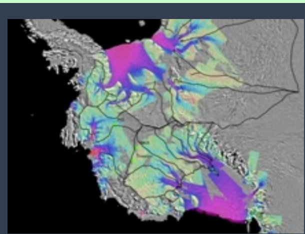
- **NASA ISRO SAR Mission**
  - A dedicated U.S. and Indian InSAR mission (L-band, S-band) optimized for studying hazards and global environmental change
- **NISAR Science Drivers**
  - **Understand the dynamics of carbon storage and uptake in wooded, agricultural, wetland, and permafrost systems**
  - **Understand the response of ice sheets to climate change and the interaction of sea ice and climate**
  - **Determine the likelihood of earthquakes, volcanic eruptions, and landslides**
- **Data to be distributed freely**

Ecosystem Structure



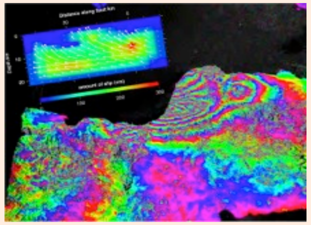
Biomass disturbance; effects of changing climate on habitats and CO_2

Cryosphere



Ice velocity, thickness; response of ice sheets to climate change and sea level rise

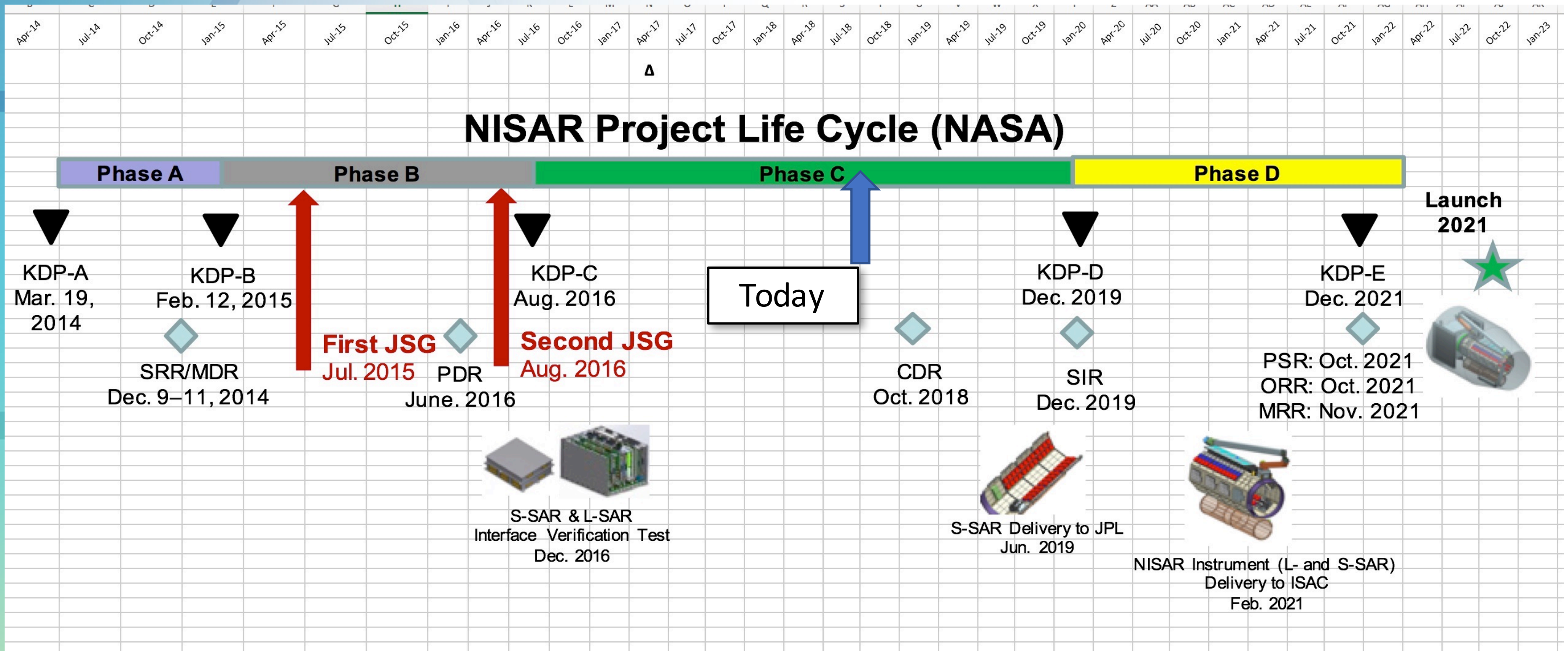
Solid Earth



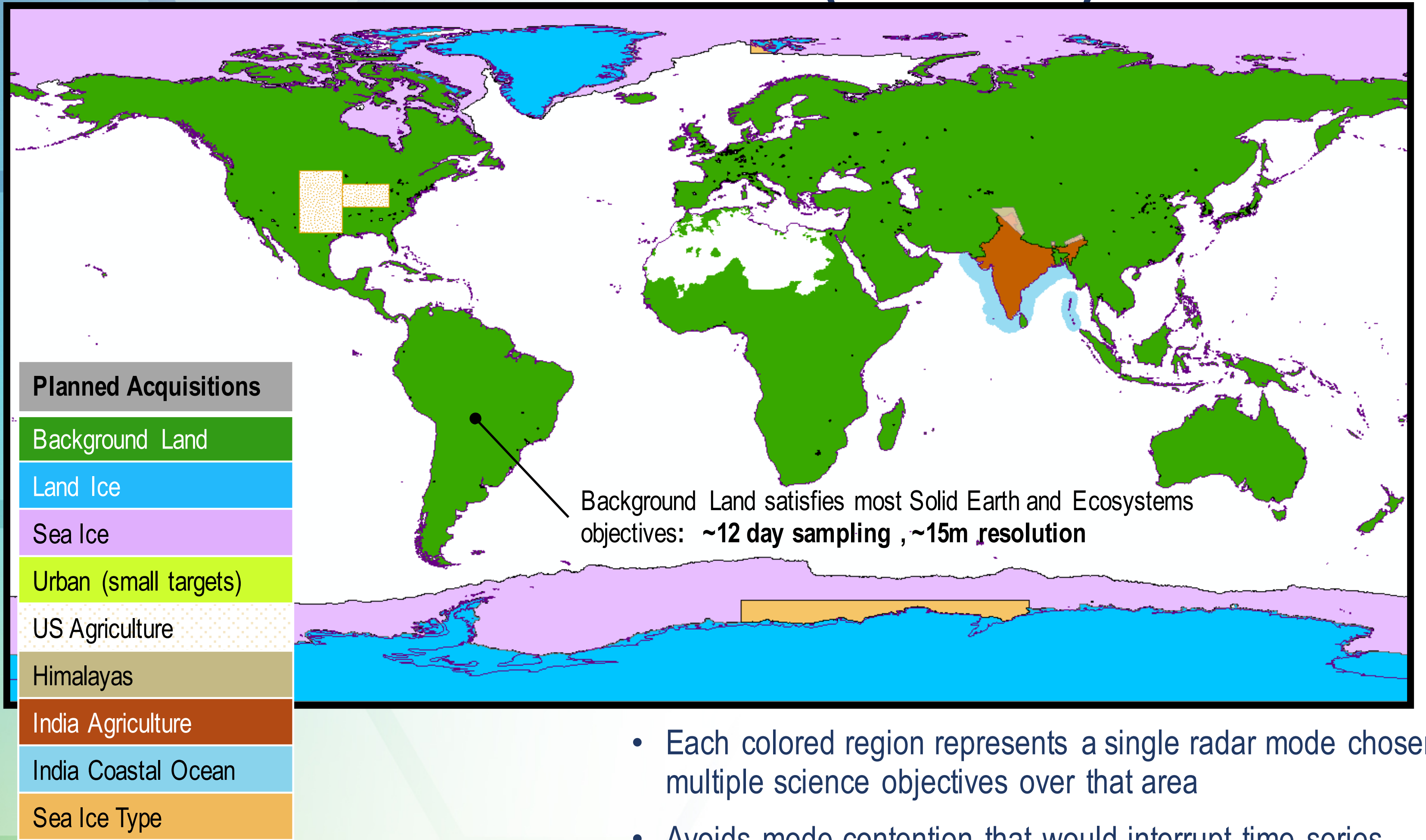
Surface deformation; geo-hazards; water resource management


NASA
NISAR
NASA - ISRO SAR Mission

Individual Activity & Timeline



Mode-Specific Science Targets in Observation Plan (Pre-2016)



- Each colored region represents a single radar mode chosen to satisfy multiple science objectives over that area
- Avoids mode contention that would interrupt time series

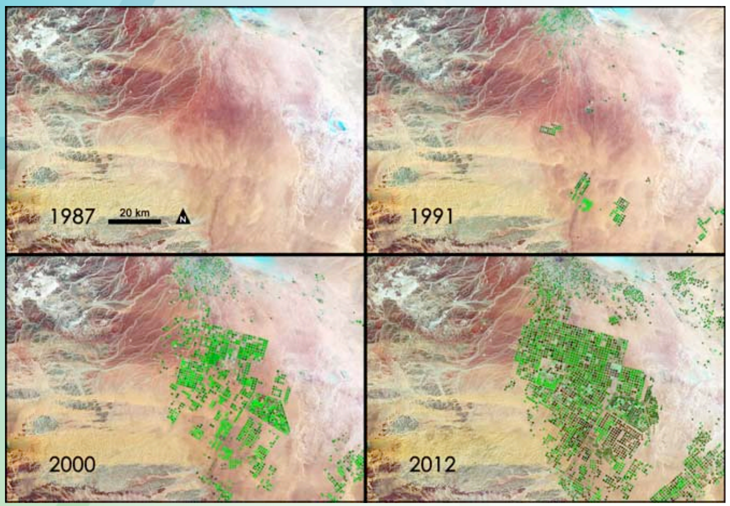
Landsat 9 Overview

Mission Objectives

- **Provide continuity in multi-decadal Landsat land surface observations to study, predict, and understand the consequences of land surface dynamics**
  - **Core Component of Sustainable Land Imaging program**

Mission Team

- **NASA Goddard Space Flight Center (GSFC)**
- **USGS Earth Resources Observation & Science (EROS) Center**
- **NASA Kennedy Space Center (KSC)**



Increase in pivot irrigation in Saudi Arabia from 1987 to 2012 as recorded by Landsat. The increase in irrigated land correlates with declining groundwater levels measured from GRACE (courtesy M. Rodell, GSFC)

Mission Parameters

- **Single Satellite, Mission Category 1, Risk Class B**
  - 5-year design life after on-orbit checkout
  - At least 10 years of consumables
- **Sun-synchronous orbit, 705 km at equator, 98° inclination**
- **16-day global land revisit**
- **Partnership: NASA & USGS**
  - NASA: Flight segment & checkout
  - USGS: Ground system and operations
- **Category 3 Launch Vehicle**
- **Launch: Management Agreement - December 2020**
  Agency Baseline Commitment – November 2021

Instruments

- **Operational Land Imager 2 (OLI-2; Ball Aerospace)**
  - Reflective-band push-broom imager (15-30m res)
  - 9 spectral bands at 15 - 30m resolution
  - Retrieves data on surface properties, land cover, and vegetation condition
- **Thermal Infrared Sensor 2 (TIRS-2; NASA GSFC)**
  - Thermal infrared (TIR) push-broom imager
  - 2 TIR bands at 100m resolution
  - Retrieves surface temperature, supporting agricultural and climate applications, including monitoring evapotranspiration

Spacecraft (S/C) & Observatory Integration & Test (I&T)

- **Northrop Grumman Innovation Systems (NGIS), formerly Orbital ATK (OA)**

Launch Services

- **United Launch Alliance (ULA) Atlas V 401**

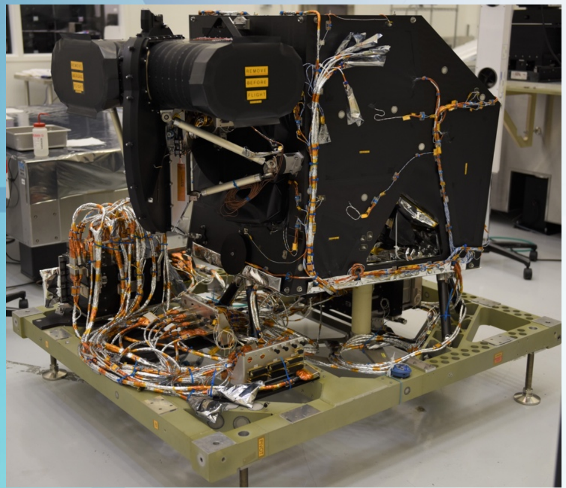
Mission Operations Center (MOC) and Mission Operations

- **General Dynamics Mission Systems (GDMS)**

Landsat 9 Development Status

- **Landsat 9 is on target for December 2020 launch**
- OLI-2 instrument undergoing Integration and Test (I&T) at Ball
  - Spatial & radiometric performance testing through 2018
  - OLI-2 Pre-Environmental Review (PER) January 2019
  - On target for mid-2019 delivery to spacecraft
- TIRS-2 being integrated at GSFC
  - Initial performance testing completed winter 2017/18 – focus, spatial performance, and stray light performance very good
  - Successful PER held August 2018
  - On target for mid-2019 delivery to spacecraft
- Spacecraft under development at NGIS; successful CDR held February 2018
- Ground system being developed by USGS
  - GS CDR to be held Sept 2018; Initial Ground Readiness Tests begin Feb 2019
  - USGS is now adopting Level-2 / Analysis Ready Data (ARD) as the standard product for L9
    - Gridded, tiled, “stackable” images
    - Processed to surface reflectance (SR) and surface temperature (ST)
    - Will continue to produce the Level-1 product

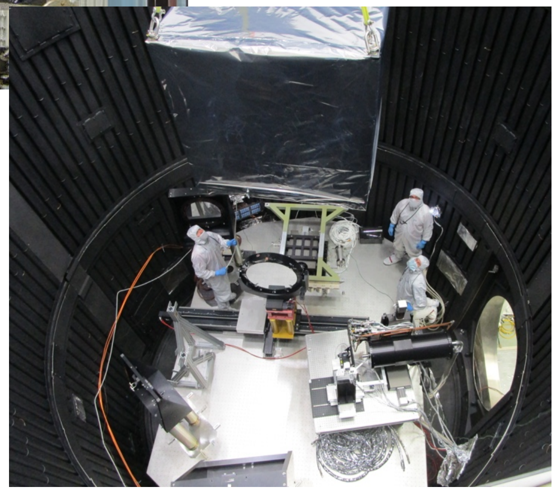
Landsat 9 Hardware

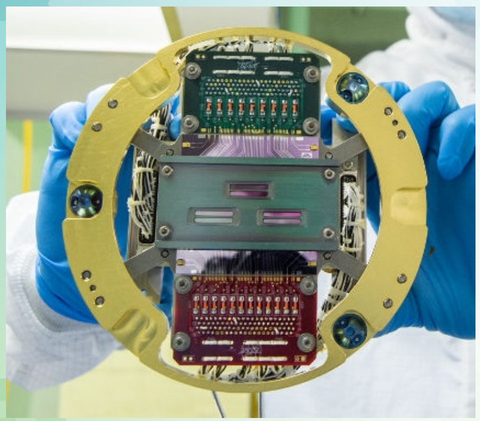


OLI-2 Assembled for Spatial Testing

Installation of the TIRS-2 Telescope and Detector into the Structure

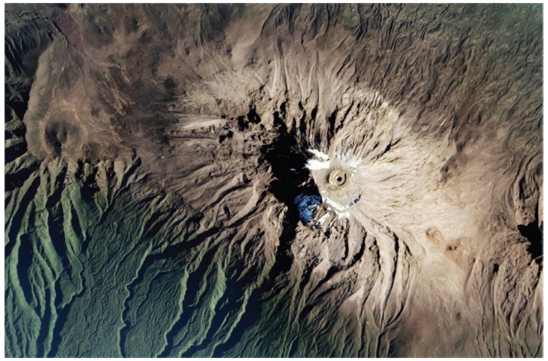
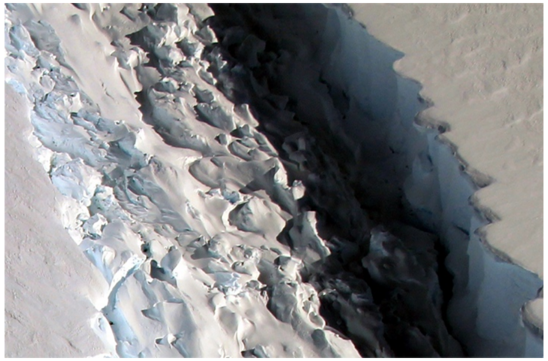
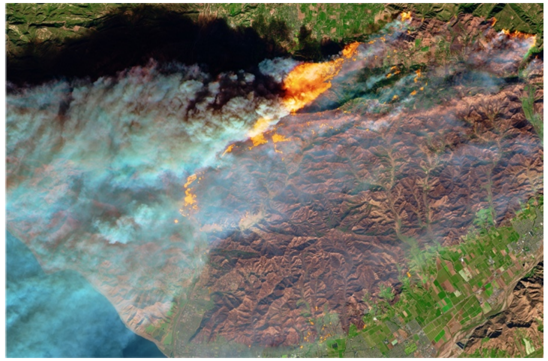
OLI-2 being lowered into the Brutus chamber for Spatial Testing





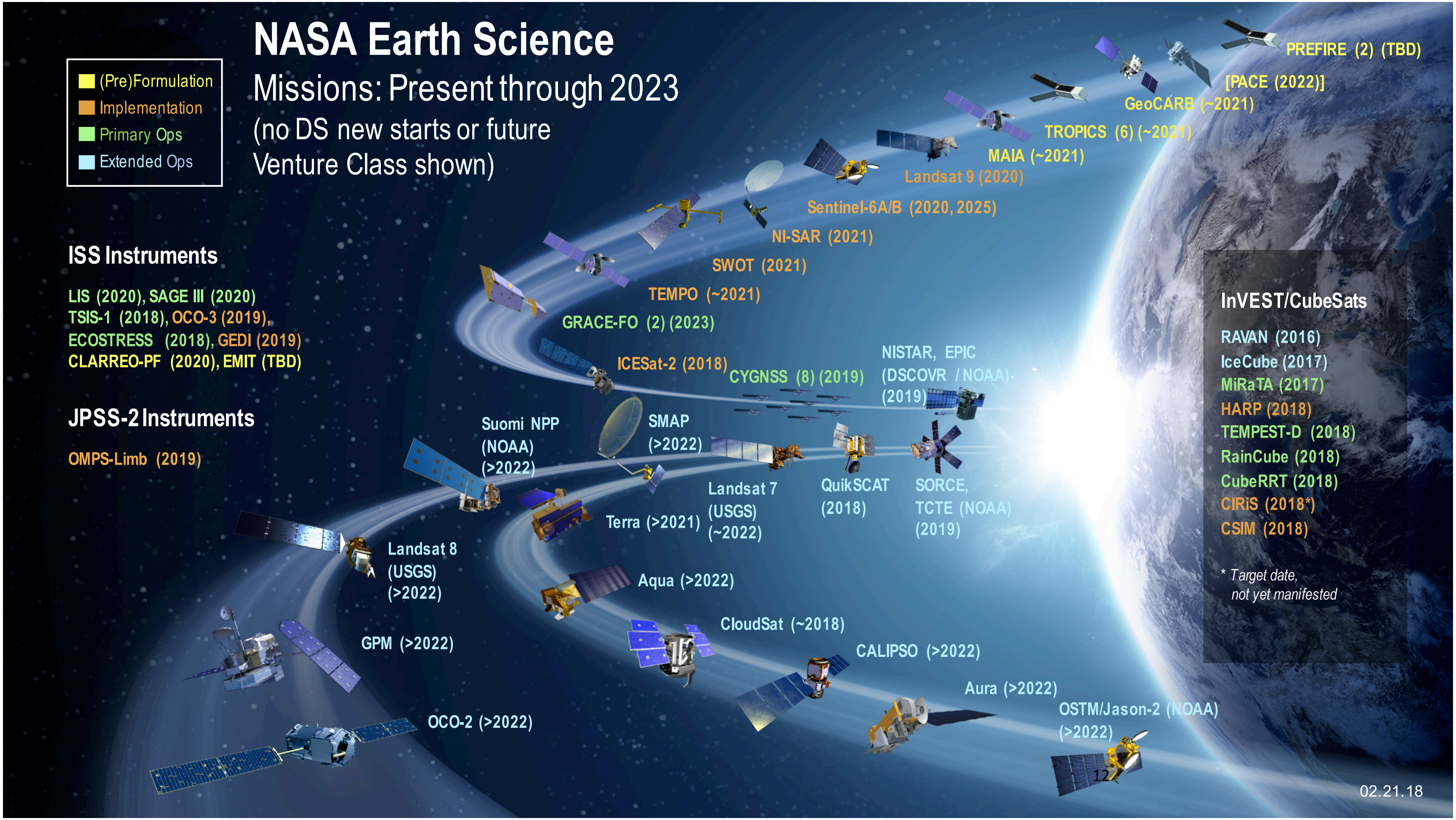
TIRS-2 Flight Detector With Filters

SCIENCE

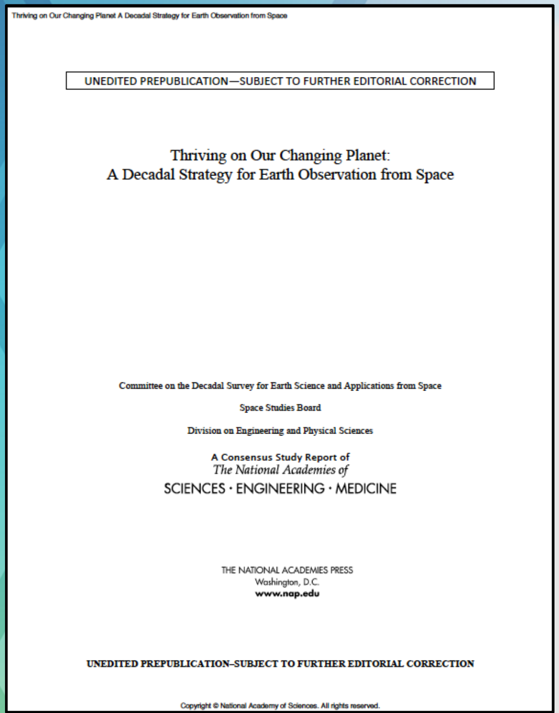
NASA Earth Science 2017 Decadal Survey Planning

David B. Jarrett
Program Executive
Earth Science Division
NASA Headquarters


NASA Earth Science
Missions: Present through 2023
(no DS new starts or future Venture Class shown)
(Pre)Formulation
Implementation
Primary Ops
Extended Ops
ISS Instruments
LIS (2020), SAGE III (2020)
TSIS-1 (2018), OCO-3 (2019),
ECOSTRESS (2018), GEDI (2019)
CLARREO-PF (2020), EMIT (TBD)
JPSS-2 Instruments
OMPS-Limb (2019)
PREFIRE (2) (TBD)
[PACE (2022)]
GeoCARB (~2021)
TROPICS (6) (~2021)
MAIA (~2021)
Landsat 9 (2020)
Sentinel-6A/B (2020, 2025)
NI-SAR (2021)
SWOT (2021)
TEMPO (~2021)
GRACE-FO (2) (2023)
ICESat-2 (2018)
CYGNSS (8) (2019)
NISTAR, EPIC (DSCOVR / NOAA) (2019)
Suomi NPP (NOAA) (>2022)
SMAP (>2022)
Landsat 7 (USGS) (~2022)
QuikSCAT (2018)
SORCE, TCTE (NOAA) (2019)
Terra (>2021)
Landsat 8 (USGS) (>2022)
Aqua (>2022)
GPM (>2022)
CloudSat (~2018)
CALIPSO (>2022)
Aura (>2022)
OCO-2 (>2022)
OSTM/Jason-2 (NOAA) (>2022)
InVEST/CubeSats
RAVAN (2016)
IceCube (2017)
MiRaTA (2017)
HARP (2018)
TEMPEST-D (2018)
RainCube (2018)
CubeRRT (2018)
CIRiS (2018*)
CSIM (2018)
* Target date, not yet manifested
02.21.18

2017 Decadal Survey Implementation Recommendations

2017 DECADAL SURVEY


Thriving on Our Changing Planet A Decadal Strategy for Earth Observation from Space

UNEDITED PREPUBLICATION—SUBJECT TO FURTHER EDITORIAL CORRECTION

Thriving on Our Changing Planet:
A Decadal Strategy for Earth Observation from Space

Committee on the Decadal Survey for Earth Science and Applications from Space

Space Studies Board

Division on Engineering and Physical Sciences

A Consensus Study Report of
The National Academies of
SCIENCES · ENGINEERING · MEDICINE

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

UNEDITED PREPUBLICATION–SUBJECT TO FURTHER EDITORIAL CORRECTION

- Recommends an **"Earth Venture Continuity"** measurement strand with a $150M full mission cost "cap" as an addition to the existing Venture-class program

- Identifies a new **"Designated Observables"** program element for cost-capped, medium- and large-size missions/observing systems for mandatory acquisition that will address five of the highest-priority Earth observation needs (see next slide)
  - Elements of this program are considered foundational elements of the next decade's observations

- Introduces a new, competed **"Earth System Explorers"** flight line with a $350M cost constraint that will address three observables to be chosen by the NASA Earth Science Division (ESD) from among six identified in the Decadal Survey

- Calls for **"Incubation Program"** between Technology development, Research & Analysis, and Flight missions to mature specific technologies for important – but presently immature – measurements (preparation for next Decadal Survey)

- Decadal new mission budget wedge opens only in late Fiscal Year 2021

Designated Observables Summary (from DS)

Observable	Science/Applications Summary	Candidate Measurement Approach	ESAS maximum cost
Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their effects on climate and air quality	Backscatter lidar and multichannel/multi-angle/polarization imaging radiometer flown together on the same platform	CATE Cap **$800M**
Clouds, Convection, And Precipitation	**Coupled cloud-precipitation state and dynamics** for monitoring global hydrological cycle and understanding contributing processes including cloud feedback	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	CATE Cap **$800M**
Mass Change	**Large-scale Earth dynamics** measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	Est Cap **$300M**
Surface Biology and Geology	**Earth surface geology and biology**, ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass	Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR	CATE Cap **$650M**
Surface Deformation and Change	**Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	Est Cap **$500M**

CATE – Cost and Technical Evaluation

Designated Observable Studies

- ESD will fund 4 mission/observing system studies at a baseline level of $2M per year
  - Surface Biology and Geology (SBG) (<$650M full NASA cost)
  - Combined Aerosols/Clouds, Convection and Precipitation (A-CCP) (<$1.6B full NASA cost)
  - Surface Deformation and Change (SDC) (<$500M full NASA cost)
  - Mass Change (MC) (<$300M full NASA cost)

- The DO studies aim to identify and evaluate observing system architectures and approaches that might improve the overall observing systems (increased capability and/or resilience, and/or reduced costs).

- ESD is taking a broad approach to addressing the observation architectures for the DOs. The studies will initially examine and evaluate the costs and benefits of observing system architectures that include a mix of NASA, international, interagency, and/or commercial spaceborne assets and data products, as appropriate.

- The SBG and A-CCP studies are expected to result in the initiation of <u>at most 2 projects</u> in the FY21/22 timeframe approximately as follows: DO #1 – 10/2021; DO #2 – 4/2022

- Other projects resulting from the DO studies are expected to be initiated no earlier than FY24.

Surface Biology and Geology (SBG) Designated Observable Study Plan

Objectives

- Establish research and applications questions for SBG looking to the Decadal Survey and prior HyspIRI questions
- Engage SBG end users and stakeholders in the above process
- Use a science and applications traceability framework to derive observing system requirements from questions
- Explore domestic and international partnerships
- Develop, assess, and design candidate architectures

Scope/Implementation

- **Phase 1** – Development of Candidate Architectures
- **Phase 2** – Assessment of Potential Architectures for Cost-effective SBG Observations
- **Phase 3** – Design of Recommended SBG Architecture and Preparation of Mission Concept Review Material
- **Phase 4** – Preparation of End of Study Report

Timeline

- August 2018 – Final HyspIRI Workshop/Initial SBG Workshop
- September 2018 – HyspIRI Final Report
- October 2018 – Initiate SBG Study Plan Funding
- December 2018 – Parallel and connected activities of the Research and Applications, Architecture Formulation, and Cost Estimation technical teams
- January 2019 to September 2021 – Assessment of candidate architectures and design of SBG observing system concept
- December 2021 (?) – Final Report, Mission Concept Review

Participants

- HQ – Turner, Phillips, Bontempi, Jarrett, Doorn SBG Leads
- Study Coordinator – JPL/Jamie Nastal
- GSFC, ARC, LaRC, MSFC study partners
- USGS, USDA, NOAA, SI, etc. – Government Participants
- Academia
- Industry
- ESA, SRON, IAVCEI, etc. – International Participants

International Engagement

- ESD has conducted focused Decadal Survey telecons/meetings with key international partners
  - CNES, CSA, DLR, ESA, EUMETSAT, ISRO, JAXA
  - Bilateral, HQ-level, face-to-face meetings planned over the next 6 months
  - Some directed international partnerships may originate from ESD
- Centers are explicitly encouraged to discuss and explore possible observable implementation approaches with international partners
- ESD will make final partnership determinations and then codify necessary international agreements

For more information

https://science.nasa.gov/earth-science/decadal-surveys

Back-up

Science Observing/Operations Modes (Pre-2016)

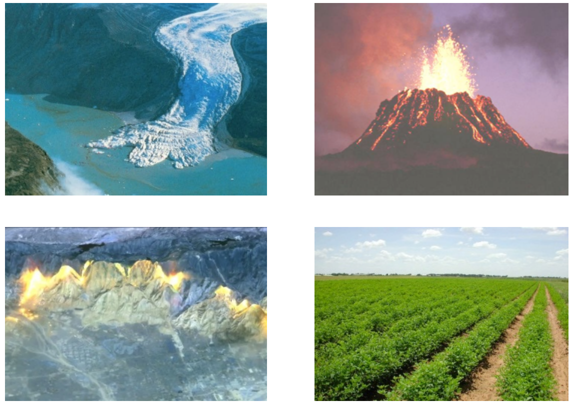
- Observation strategy employs a small subset of possible modes

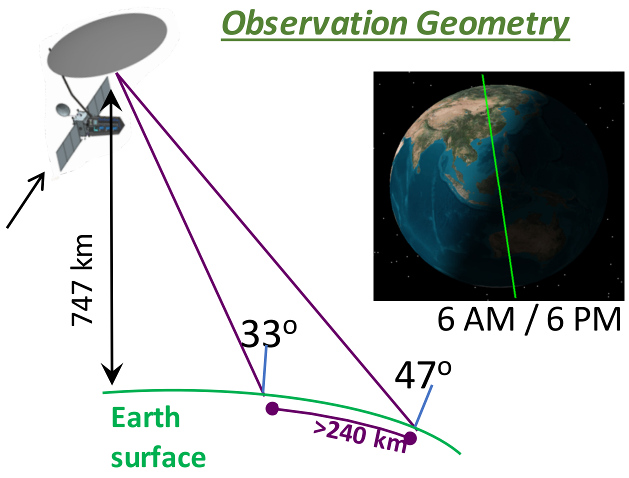
Observation Strategy	L-band		S-band		Culling Approach	
Science Target	**Mode+**	**Resolution**	**Mode**	**Resol.**	Sampling	Desc Asc
Background Land	DP HH/HV	12 m x 8 m			cull by lat	
Land Ice	SP HH	3 m x 8 m			cull by lat	
Sea Ice Dynamics	SP VV	48 m x 8 m			s = 1 p	
Urban Areas		6 m x 8 m			s = 1 p	
US Agriculture	QP HH/HV VV/VH				s = 1 p	
Himalayas			CP RH/RV		s = 1 p	
India Agriculture					s = 1 p	
India Coastal Ocean			DP HH/HV or VV/VH		s = 1 p	
Sea Ice Types	DP VV/VH				s = 3 p	

NISAR Concept Science Observation Overview

NISAR Characteristic:	Would Enable:
L-band (24 cm wavelength)	Low temporal decorrelation and foliage penetration
S-band (12 cm wavelength)	Sensitivity to light vegetation
SweepSAR technique with Imaging Swath > 240 km	Global data collection
Polarimetry (Single/Dual/Quad)	Surface characterization and biomass estimation
12-day exact repeat	Rapid Sampling
3 – 10 meters mode-dependent SAR resolution	Small-scale observations
3 years science operations (5 years consumables)	Time-series analysis
Pointing control < 273 arcseconds	Deformation interferometry
Orbit control < 500 meters	Deformation interferometry
> 30% observation duty cycle	Complete land/ice coverage
Left/Right pointing capability	Polar coverage, north and south

NISAR Would Uniquely Capture the Earth in Motion

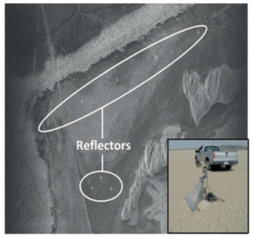


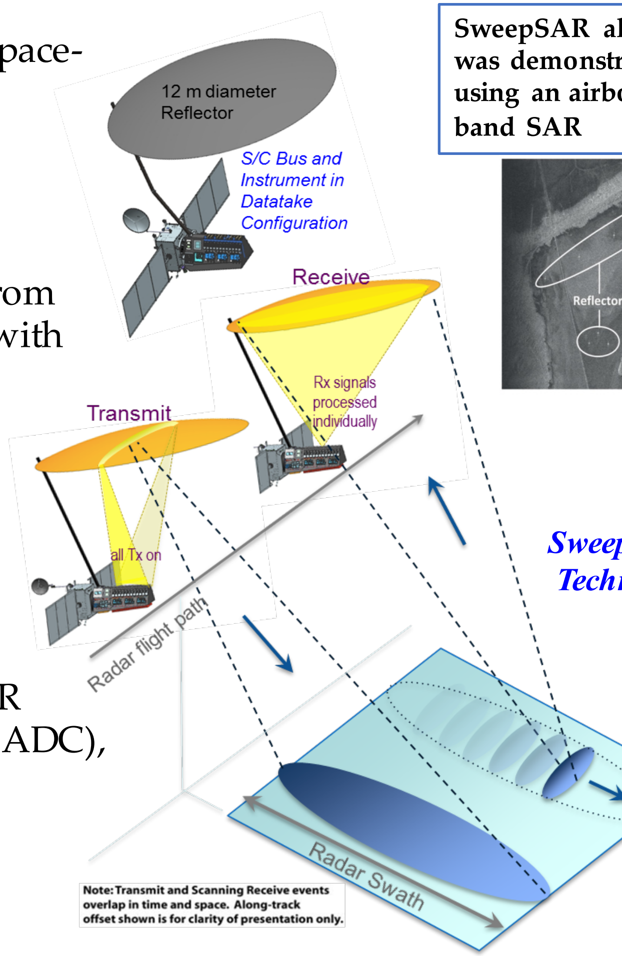


Radar Payload Concept

- World's first dual frequency (L- and S- band) space-borne SweepSAR
- Repeat pass interferometry
- Fully polarimetric SAR capability
- Array-fed reflector (boresight at ~37 degrees from nadir, transmitting a fan beam, and receiving with multiple pencil beams)
  - Shared reflector for both L- and S-bands
  - Separate L- and S-band feeds
  - F/D = 0.75
  - Incidence angles: 30 – 42 degrees
- Observatory pointing control +/- 273 arcsec
- Active front-end electronics, high efficiency T/R module, high rate analog-to-digital converter (ADC), and on-board processing

SweepSAR algorithm was demonstrated using an airborne Ka-band SAR





Sweep SAR Technique

Aerosol – Cloud, Convection and Precipitation (A-CCP) Designated Observable Study Plan

Objectives

- Refine Science Traceability Matrices (STM) from ACE and add STMs for aerosol air quality, convection and precipitation
- Engage NASA center, university, US government agencies, commercial and international partners
- Use refined STMs as the scientific basis to design, develop and assess viable candidate architectures for making necessary observations utilizing satellite remote sensing, airborne measurements and surface-based sensors

Scope/Implementation

- **Phase 1** – Develop Science Value Framework
- **Phase 2** – Refine and Develop STMs
- **Phase 3** – Develop A-CCP DO Architecture(s) including documentation for Mission Concept Review
- **Phase 4** – Preparation of Final Study Report

Timeline

- September 2018 – Start Development of Science Value Framework
- October 2018 – Initiate Science Group work on STMs
- January 2019 – Complete STMs
- January/February 2019 – Meeting of Full A-CCP Study Team
- March 2019 – Blue Sky Study
- April/May 2019 – Start Architecture Studies
- Early 2022 – Final Report, Mission Concept Review

Participants

- HQ – Maring, Jackson, Lefer, Dutta, Edwards, Haynes
- Study Coordinators – Cutlip (GSFC), Vane (JPL), Trepte (LaRC)
- NASA Centers - GSFC, JPL, LaRC, MSFC, ARC, GRC
- Other Expected US Participants NOAA, EPA, Universities, Commercial
- Hoped for International Partners – CNES, JAXA, ESA, SRON, …

Surface Deformation and Change (SDC) Designated Observable Study Plan

Objectives

- Determine cost-effective SAR-based architecture to implement the Surface Deformation and Change Observable
- Keep other science and applications that SAR can enable in the trade space
- Engage emerging best and new practices in industry to maximize engagement and exploitation of commercial sector capabilities and interests, including smallsat constellations
- Explore international partnerships to leverage capability and reduce cost

Scope/Implementation

- Include SAR-based architectures that support broader science/applications observables beyond geodetics in trades
- **Phase 1 –** Engage user communities to define requirements and 5-6 candidate architectures; establish value framework
- **Phase 2 –** Evaluate science/applications value; down-select to 2 top candidates for detailed evaluation; down-select to concept
- **Phase 3 –** Phase A study leading to Mission Concept Review
- **Phase 4 –** Final Report and MCR prep

Timeline

- October 2018 – Study Kickoff
- October 2019 – Complete Performance Tool Development
- March 2020 – Complete Requirements Definition
- March 2021 – Begin assessment of candidate architectures
- March 2022 – Downselect to concept
- March 2023 – Complete design concept
- October 2023 – Deliver Final Report
- December 2023 – Conduct Mission Concept Review

Participants

- HQ Leads: PS–Bawden, Margolis: PE–Slonaker: PA– Green
- JPL – Study Lead (P. Rosen, Study Coordinator)
- ARC, GSFC, LaRC, MSFC study partners
- USGS, NOAA, NGA government participants
- Academia
- Industry

Mass Change (MC) Designated Observable Study Plan

Objectives

- Identify and characterize a diverse set of high value MC observing architectures responsive to Decadal Survey, preserving the fundamental approach that MC is observed through gravitational forces acting on the space craft(s).
- Assess the cost effectiveness of each of the studied architectures.
- Perform sufficient in-depth design of one or two select architectures to enable rapid initiation of a Phase A study

Scope/Implementation

- Examine (1) novel approaches considering emerging capabilities, such as industry spacecraft, launch vehicles, and "data buy" opportunities, and (2) innovative approaches and enabling techniques, such as small satellite buses, constellations using only positioning information, compact, low-power electronic accelerometers and drag compensation systems.
- Candidate Mission Architectures will maintain continuity of measurements and/or explore:
    - Ground water and water storage mass change
    - Land ice contributions to seal level rise
    - Ocean mass change & heat content (when combined w/altimetry)
    - Glacial isostatic adjustment
    - Earthquake mass movement.
    - Operational applications (drought, hazards, agriculture, etc.)

Timeline

- **Oct 2018 – Phase 1 – Develop Candidate Architectures:** Engage user communities to define requirements and establish capabilities, and create value framework
- **Oct 2019 – Phase 2 – Assessment of Candidate Architectures:** Evaluate science and applications value, down-select to top candidates for detailed evaluations
- **June 2020 – Phase 3 – Architecture Design of top candidate(s):** Phase A study leading to Mission Concept Review
- **Jan 2021 – Phase 4 – Develop final report and Preparation of Mission Concept Review**
- **Sept 2021 – Delivery of final report and end of Study:** includes required observational capabilities of mission concept that may be used for competitive procurement of mission components.

Participants

- NASA – L. Tsaoussi, MC HQ Lead
- JPL – Study Lead (B. Bienstock, Study Coordinator)
- ARC, GSFC, LaRC study partners
- Academia (U. of Texas, U. South Florida, U. Colorado)
- International (DLR, ESA)
- US government (NOAA, USGS)
- Industry