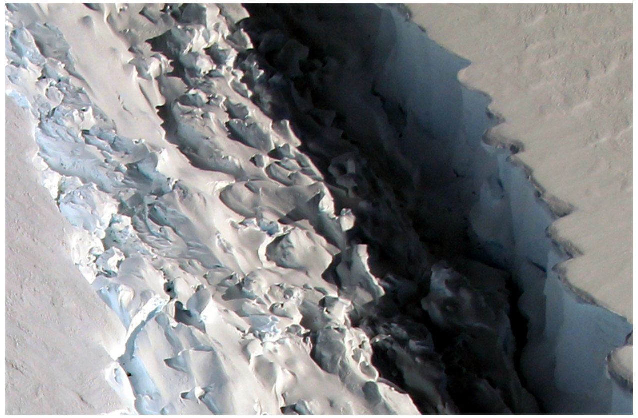
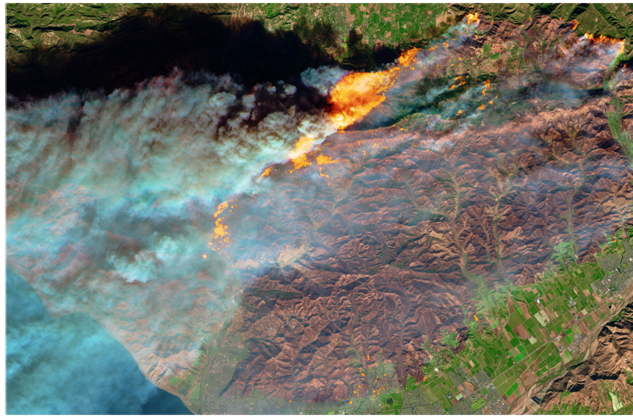
SCIENCE

Surface Deformation and Change Architecture Study



NASA HQ Perspective

Dr. Gerald Bawden

Program Scientist – NISAR/SDC

NASA Headquarters

Gerald.Bawden@nasa.gov

NASA Center Perspective

Dr. Paul Rosen

Project Scientist – NISAR/SDC Study Lead

Jet Propulsion Laboratory, California Institute of Technology

Paul.A.Rosen@jpl.nasa.gov

Copyright 2020 California Institute of Technology. Government sponsorship acknowledged. Pre-decisional. For discussion purposes only.

Jet Propulsion Laboratory
California Institute of Technology

NASA EARTH FLEET

OPERATING & FUTURE THROUGH 2023

SWOT (CNES) 2022
TROPICS (6) 2020
LANDSAT-9 (USGS) 2021
SENTINEL-6 Michael Freilich/B (ESA) 2020, 2025
NISAR (ISRO) 2022
GEOCARB 2022
TSIS-2 2023
MAIA 2022
PREFIRE (2) 2022
TEMPO 2022
GLIMR ~2026
PACE 2024 (NSO)
ICESAT-2 2021
GRACE-FO (2) (GFZ) 2023
CYGNSS (8) 2020
NISTAR, EPIC (DSCOVR/NOAA) 2020
CLOUDSAT (CSA) 2021
TERRA (JAXA, CSA) >2021
AQUA (JAXA, AEB) >2022
AURA (NSO, FMI, UKSA) >2022
CALIPSO (CNES) >2022
GPM (JAXA) >2022
LANDSAT 7 (USGS) ~2022
LANDSAT 8 (USGS) >2022
OCO-2 >2022
SMAP >2022
SUOMI NPP (NOAA) (JAXA) >2022

ISS INSTRUMENTS

EMIT 2021
CLARREO-PF 2023
GEDI 2020
SAGE III 2020
OCO-3 2022
TSIS-1 2023
ECOSTRESS 2020
LIS 2020

JPSS-2, 3 & 4 INSTRUMENTS

OMPS-Limb 2022
LIBERA 2027

03.31.20

INVEST/CUBESATS

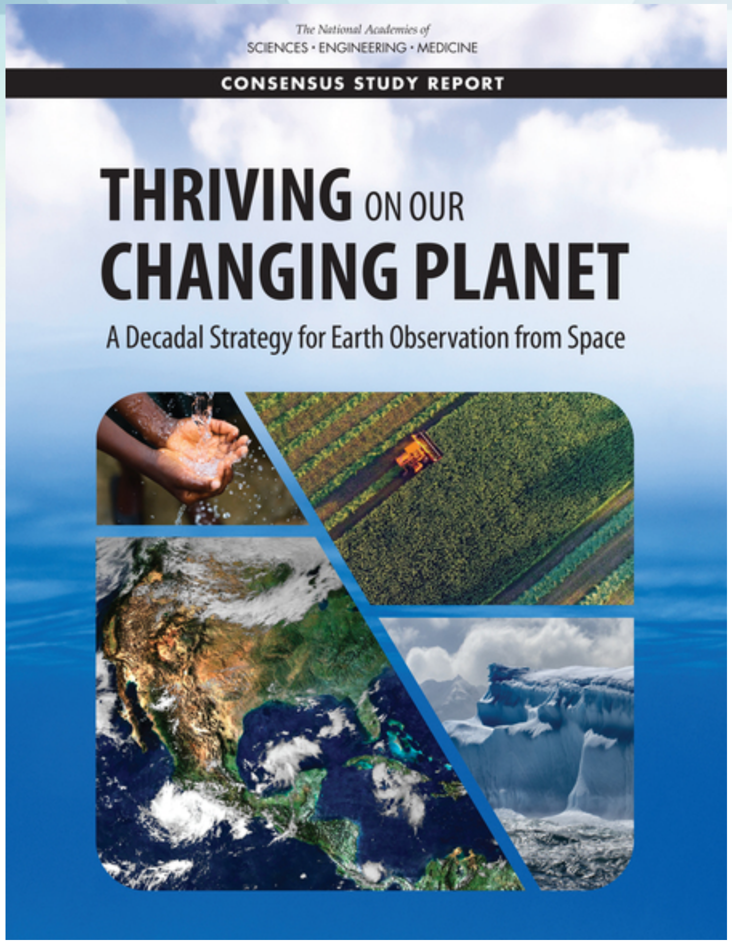
RainCube 2018
CSIM-FD 2018
CubeRRT 2018
TEMPEST-D 2018
CIRiS 2020
HARP 2020
CTIM*
HyTI*
SNoOPI*
NACHOS*

** Launch date TBD*

(PRE) FORMULATION
IMPLEMENTATON
PRIMARY OPS
EXTENDED OPS

2017 Decadal Survey Snapshot

2017 DECADAL SURVEY



- Supports the ESD (and international) *Program of Record*
- Prioritizes *observations* rather than specific missions
- Emphasis on *competition* as cost-control method
- Explicitly allows *implementation flexibility*
- Explicitly encourages *international partnerships*
- Endorses *existing balances* in ESD portfolio
- Identifies 5 "Designated" observables for mandatory acquisition:
  - Aerosols
  - Clouds, Convection, & Precipitation
  - Mass Change
  - Surface Biology & Geology
  - *Surface Deformation & Change*
- Calls for "cost-capping" essentially all missions:
  - Decadal new mission budget wedge opens only in late FY21

https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth

Observing System Priorities

TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their direct and indirect effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform	X		
Clouds, Convection, & Precipitation	**Coupled cloud-precipitation state and dynamics** for monitoring global hydrological cycle and understanding contributing processes	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	X		
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	X		
Surface Biology & ...	**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	X		
Surface Deformation & Change	**Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	X		
Greenhouse Gases	**CO_2 and methane fluxes and trends,** global and regional with quantification of point sources and identification of source types	Multispectral short wave IR and thermal IR sounders; or lidar**		X	
Ice Elevation	**Global ice characterization** including elevation change of land ice to assess sea level contributions and freeboard height of sea ice to assess sea ...	Lidar**		X	
Ozone & Trace Gases	**Vertical profiles of ozone and trace gases** (including water vapor, CO, NO_2, methane, and N_2O) globally and with high spatial resolution	UV/IR/microwave limb/nadir sounding and UV/IR solar/stellar occultation		X	
Snow Depth & Snow Water Equivalent	**Snow depth and snow water equivalent** including high spatial resolution in mountain areas	Radar (Ka/Ku band) altimeter; or lidar**			
Terrestrial Ecosystem Structure	**3D structure of terrestrial ecosystem** including forest canopy and above ground biomass and changes in above ground carbon stock from processes such as deforestation & forest degradation	Lidar**			
Atmospheric Winds	**3D winds in troposphere/PBL** for transport of pollutants/carbon/aerosol and water vapor, wind energy, cloud dynamics and convection, and large-scale circulation	Active sensing (lidar, radar, scatterometer); passive imagery or radiometry-based atmos. motion vectors (AMVs) tracking; or lidar**		X	X
Planetary Boundary Layer	**Diurnal 3D PBL thermodynamic properties and 2D PBL structure** to understand the impact of PBL processes on weather and AQ through high vertical and temporal profiling of PBL temperature, moisture and heights.	Microwave, hyperspectral IR sounder(s) (e.g., in geo or small sat constellation), GPS radio occultation for diurnal PBL temperature and humidity and heights; water vapor profiling DIAL lidar; and lidar** for PBL height			X
Surface Topography & Vegetation	**High-resolution global topography** including bare surface land topography ice topography, vegetation structure, and shallow water bathymetry	Radar; or lidar**			X

** Could potentially be addressed by a multi-function lidar designed to address two or more of the Targeted Observables

Surface Deformation & Change	**Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction

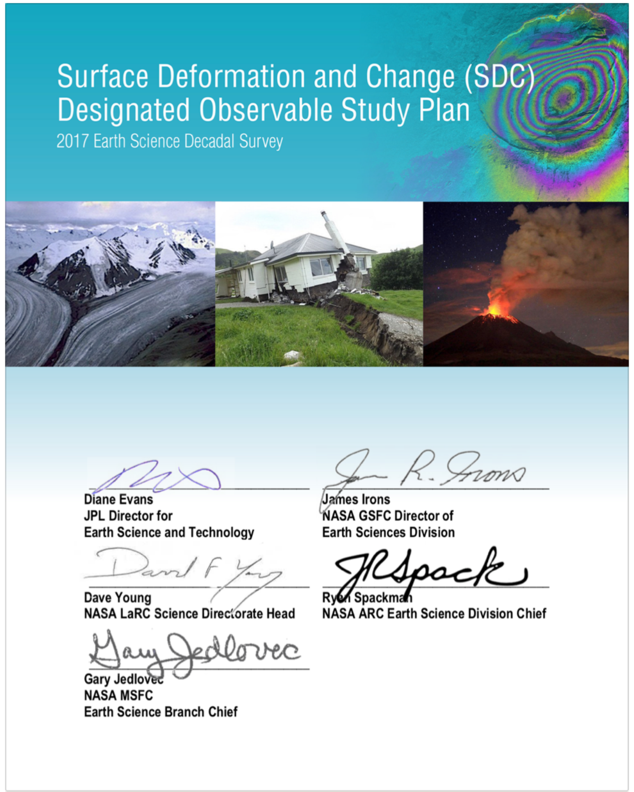
DO Mission/Observing System Implementation

- Each DO Mission/Observing System will be directed to a Center
- Each Mission/Observing System will be cost-constrained, informed by DS
  - SDC $500m cap
- Payloads will be competed by HQ
- Satellite bus expected to be procured
- Partnerships strongly encouraged
- Contributions of each mission/observing system to other ESD science objectives strongly encouraged
- SBG or some combination of Aerosol/CCP will be first DO mission/observing system to be initiated

Surface Deformation and Change – SDC

Architecture Study Objectives

- Determine cost-effective SAR-based architecture to implement the Decadal Survey's Surface Deformation and Change Observable – *SAR phase*
- Evaluate other Science and Applications that SAR can enable in the trade space – *SAR backscatter*
- 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.

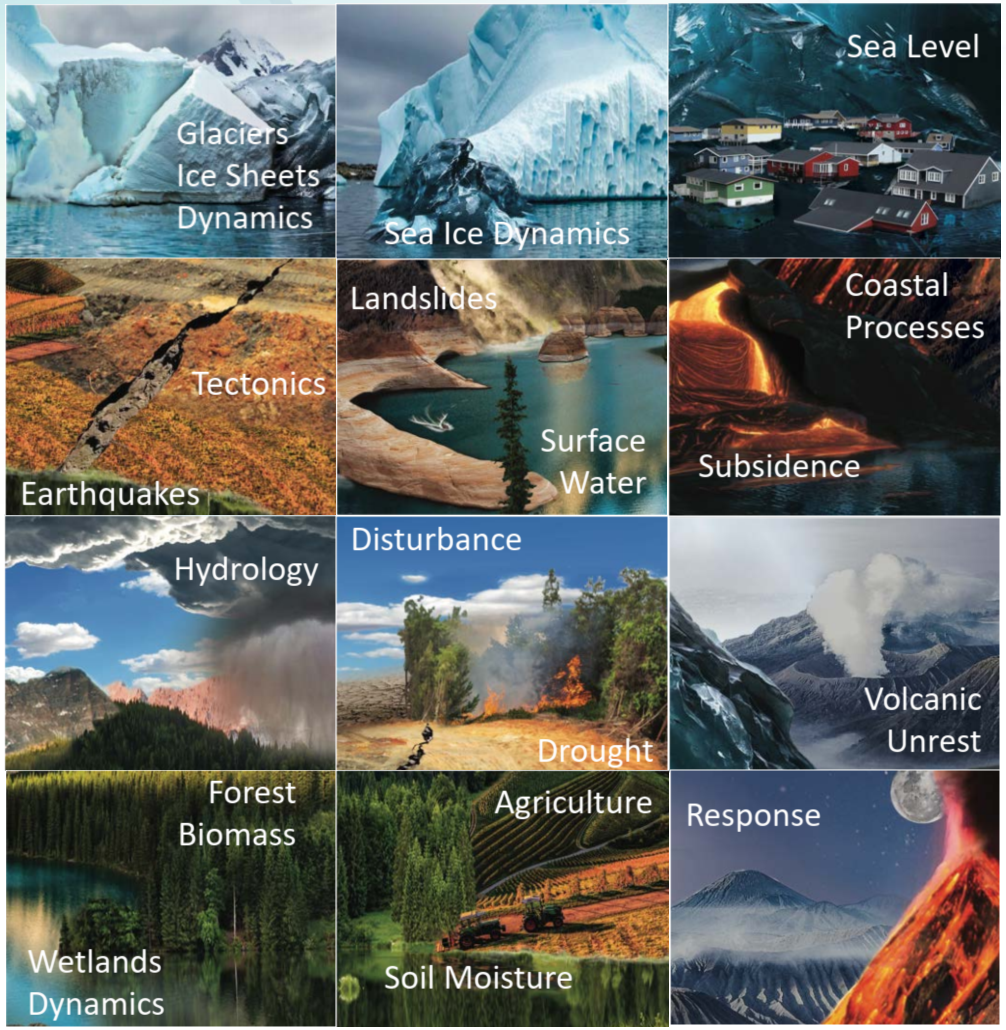


SDC Headquarters Leadership

- PS: Gerald Bawden, Hank Margolis (alt), Michael Falkowski (alt)
- PE: Mitra Dutta, Kevin Murphy (alt)
- PA: Emily Sylak-Glassman
- Study Coordinator: Paul Rosen (JPL)

SDC Goals

Serve stakeholders in the following Science Communities according to the SATM:



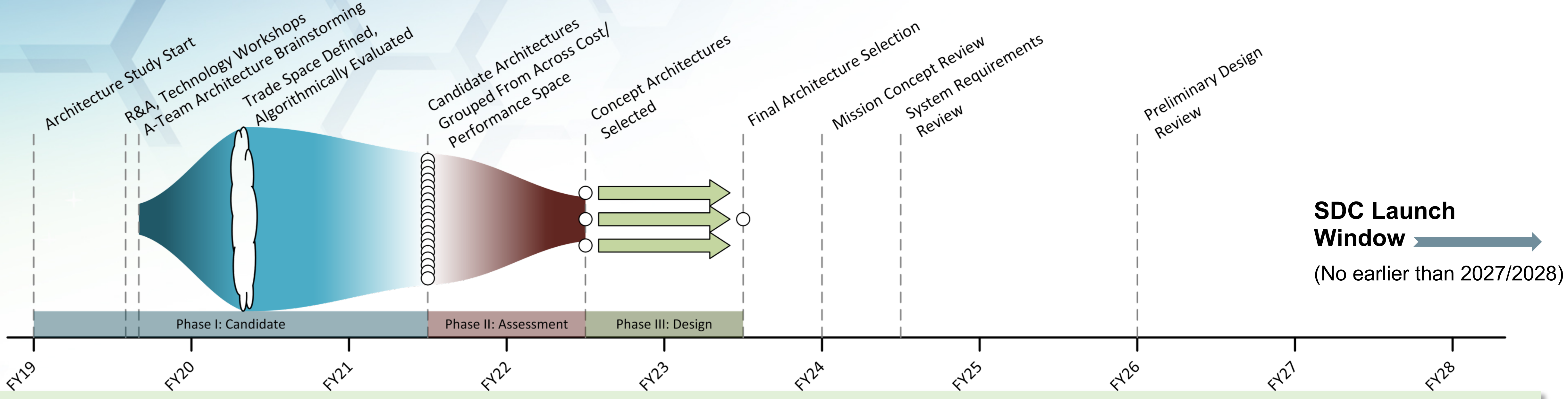
SDC Observation Goals in Decadal Survey:

- Interferometric repeat-passes at sub-weekly to daily rates.
- Resolution needs ranging from 5m to 15m
- Sensitivity to height changes between 1-10 mm
- Time series measurements from 1 mm/week to 1 mm/year
- Continuous global monitoring of all land and coastal areas
- Supplement the program of record running from 2017-2027
- Provide a plan for a 10+ year mission lifetime
- Maximum cost to NASA of $500M (Phase A-F)

Explicit NASA-specified SDC Observation Goals:

- Include radiometry, not only interferometry, in architectures
- Noise equivalent sigma-0 < -20 dB
- Ambiguities < -20 dB

SDC in relation to NISAR development and science operations



In development: ALOS-4 & LuTan-1 Launches; NISAR Launch; Commissioning + 3 yrs science ops; NISAR Extension

Proposed: ROSE-L Start Phase B2; ROSE-L Start Phase C?

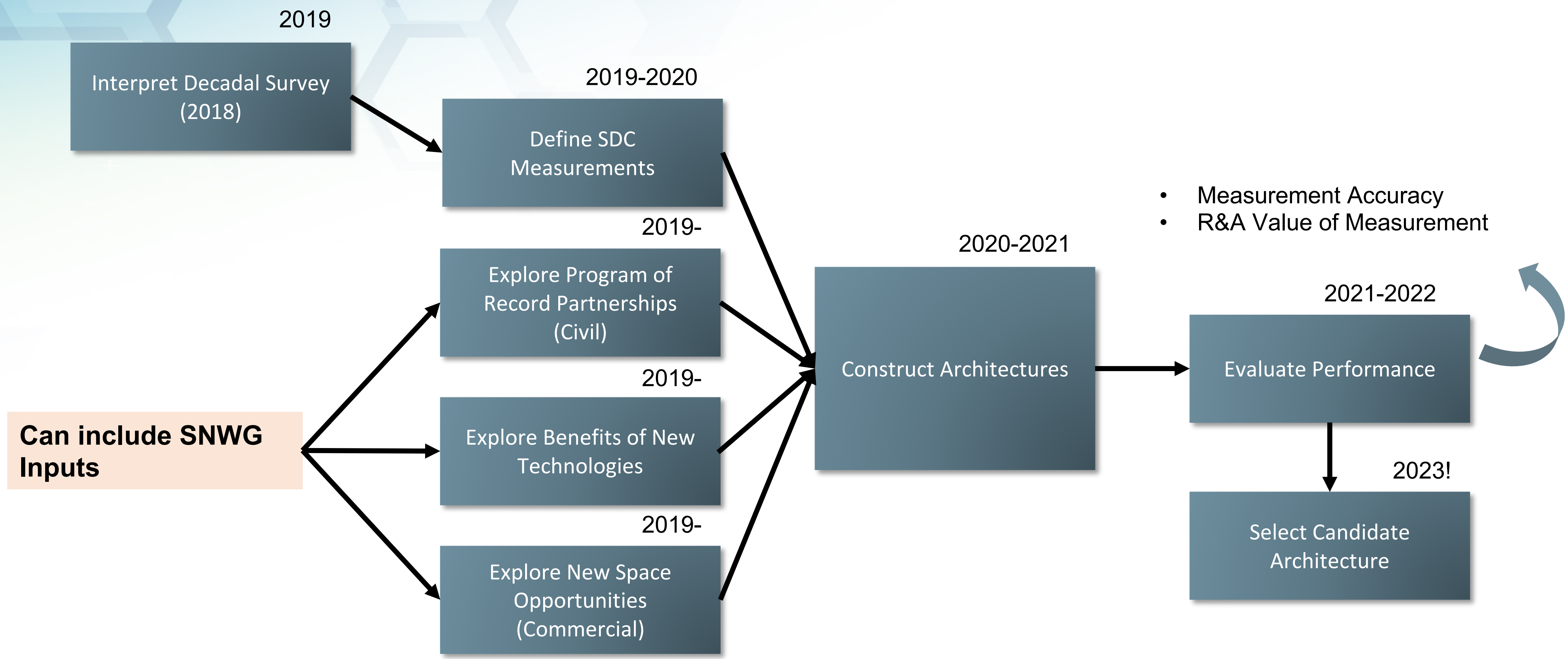
NewSpace SAR: positive slope on development curve

ROSE-LA Launch; ROSE-LB Launch

Critical period for SDC to be active and engaged

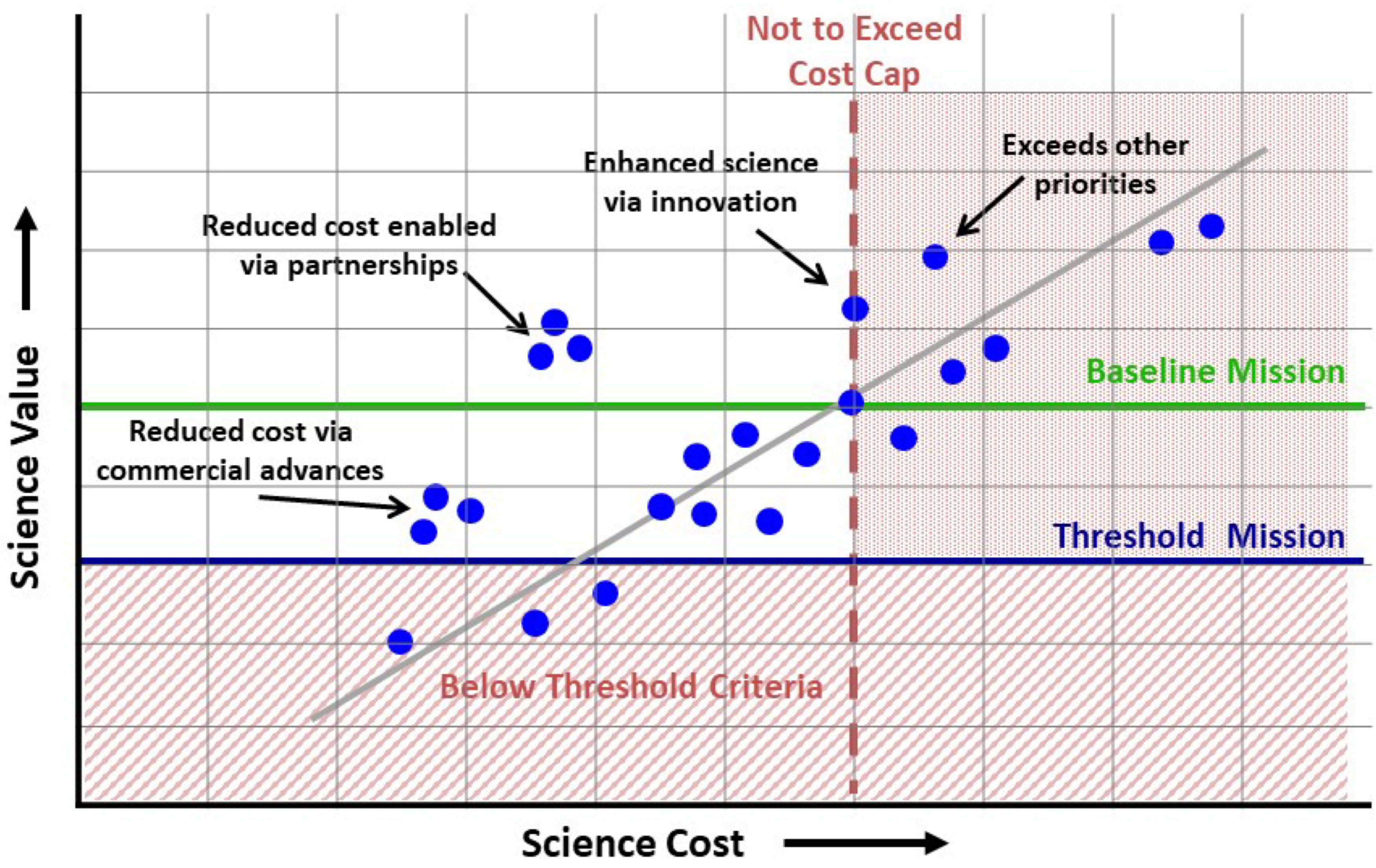
- If ROSE-L is not approved, SDC provides continuity for NISAR with a potential for augmentations in targeted observations
- If ROSE-L is approved, SDC provides in addition denser time sampling to address more challenging capabilities requested by Decadal Survey

SDC 5-year Architecture Study at a Glance



Assessing Architectures through a Science Value Framework

SDC Study Team working with Science Community to defining *Science Value*



Elements of Science Value and Science Cost

Each mission must construct its own science value metrics based on its unique aspects

- Science and Applications – What are the measurements? How accurate will they be? How will it advance the field if they are made to that accuracy? How are different disciplines evaluated against each other?
- Programmatics – are other space agencies performing similar measurements? Are there ***partner opportunities***? How will the measurements further the goals of ***other US agencies*** or international priorities? How can commercial assets replace or supplement government assets?
- Technology – Is the technology ready? If not, what investment is needed to advance the science?

Science and Applications Traceability Matrix as a Means to Prioritize Science

- The SATM allows a systematic approach to defining measurement objectives and priorities for intercomparison
- Sample at right for one cryosphere science question
- The Decadal Survey identified many such questions relevant to SDC
- SNWG needs could be characterized in a similar fashion

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable MI VI I	Measurement Parameters	Example Measurement Approaches Method	 PoR
QUESTION C-1. How much will sea level rise, globally and regionally, over the next decade and beyond, and what will be the role of ice sheets and ocean heat storage?	**C-1c.** Determine the changes in total ice sheet mass balance to within 15 Gton/yr over the course of a decade and the changes in surface mass balance and glacier ice discharge with the same accuracy over the entire ice sheets, continuously, for decades to come	Ice velocity (ice sheets):		InSAR	PoR-12
		Fast flowing outlet glaciers, grounded and floating (>50 m/yr)	Daily (targeted) to weekly (all), 1-5 m/yr horizontal accuracy, 100 m horizontal resolution		
		Slow flowing ice-sheet interiors (>50 m/yr)	Once yearly, 0.1 m/yr horizontal accuracy, 1 km horizontal resolution		
		Ice velocity (mountain glaciers: Arctic, Alaska, Patagonia, Himalayas)	Monthly, 1 m/yr horizontal accuracy, 50 m horizontal resolution		
		Shear margins (grounded and floating)	Daily to weekly, 1 m/yr horizontal accuracy, 10-25 m horizontal resolution		
		Fracture and calving:			
		Strain rates	Daily to weekly, 1 m/yr horizontal accuracy, 10-25 m horizontal resolution		
		Geometry and mélange	Amplitude-based imagery, Daily to weekly, 10-25 m horizontal resolution		
		Grounding lines (+/- 50 km of current locations)	Weekly to monthly, 30 mm vertical accuracy between acquisitions, 100 m horizontal resolution		

First SDC Research and Applications Workshop Outcomes

- Refinement of these outcomes and addition of hydrology, sea-ice, and permafrost needs underway

	Solid Earth	Cryosphere	Geohazard	Ecosystems
Coverage	Global Access	***Pan-Polar*** Access	***Localized***	Global Access
Temporal Sampling	***Daily***	***Daily***-Weekly	***Subdaily***	Weekly-Seasonal
Data Latency	Not a priority	Not a priority	***1 - 3 hours***	Generally not a priority
Amplitude/ Polarization	• Amplitude not a priority • Single-pol sufficient	• Amplitude useful • Single-pol sufficient	• Amplitude needed for several applications • Single-pol sufficient	• Amplitude essential • Multi-pol needed

Note: Airborne systems can play an important role in realizing ***localized, frequent, low-latency*** observables

Science Performance Tool as a Measurement Value Metric
Displacement, Biomass, Disturbance

Radar Parameters

Power, gain, BW, etc.

Data Types

Backscatter type
Slope

Radar Sensor Performance Tool

Radar Performance
SNR
Ambiguities
QNR
ISLR
Azimuth resolution
Range resolution
Etc.

Data Masks
Troposphere (seasonal)
Ionosphere (time of day)
Snow cover (8-day sampling)
Terrain classification map
DEM and DEM slope
Global tree height map

Ephemeris Generation Tool

SAR/InSAR Performance Tool

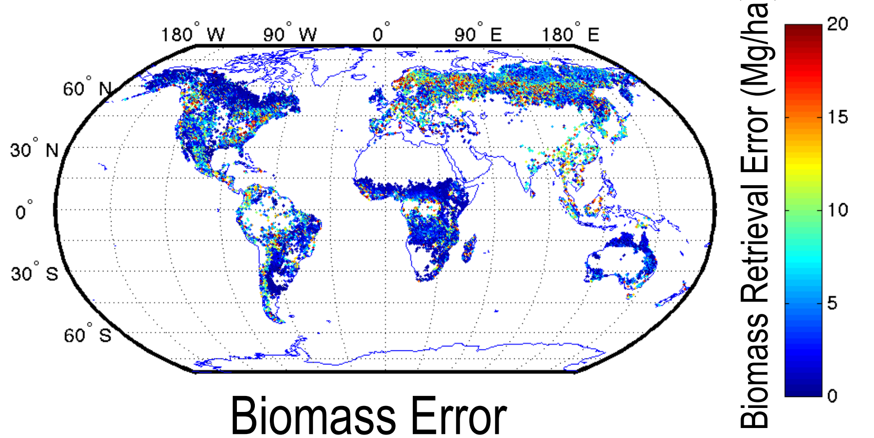
Con Ops Rules
Data priorities
Observation timelines

Mission Scenario Tool

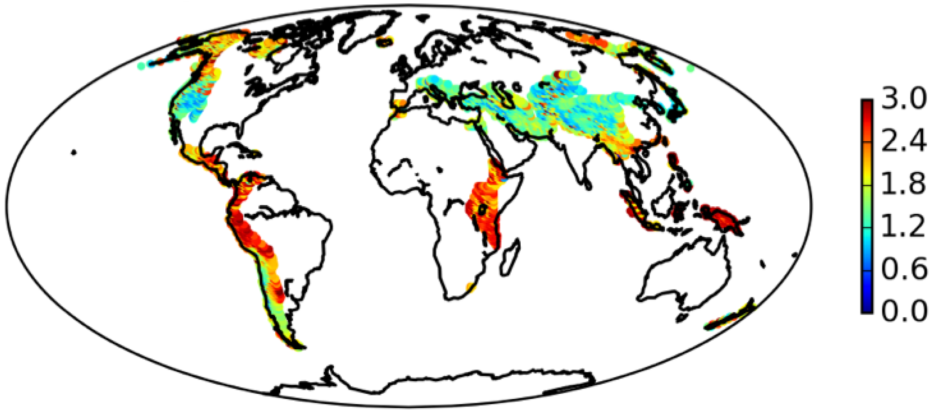
Observation List
Times points observed
Platform location
Radar mode
Incidence angle

Mission Constraints
Power
Data rate/volume
Downlink masks

L1 and L2 Parameter Performance Metrics
Deformation error
Biomass error
Disturbance error



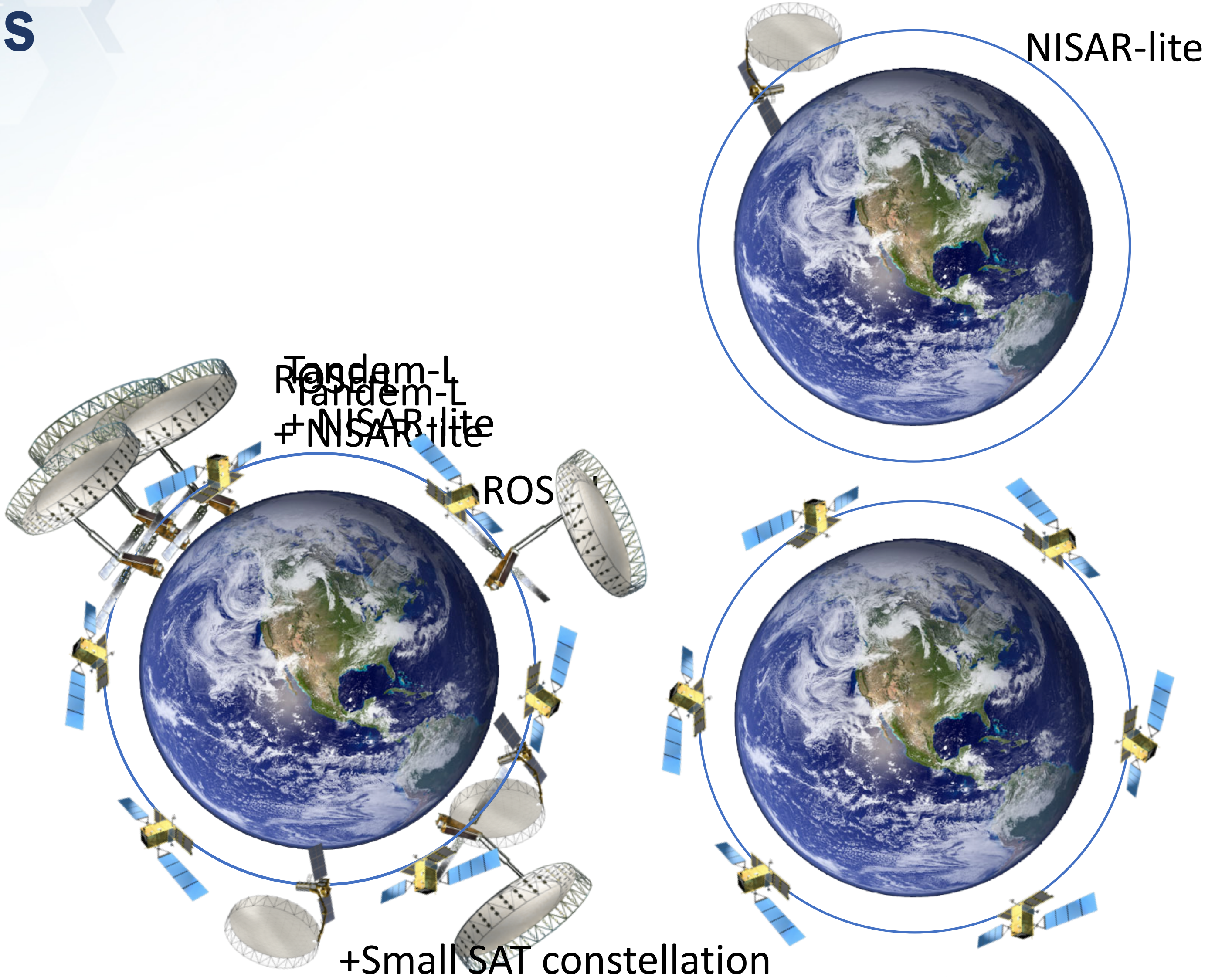
Biomass Error
(Mg/ha)



Displacement Error
5 km scale in mm/yr

Initial Candidate Architectures

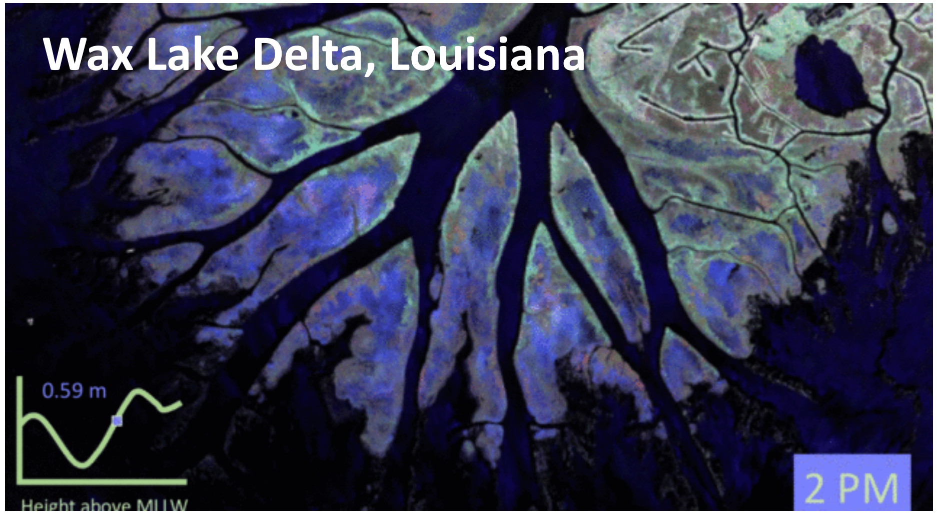
- In 2020, the **performance tool** will be **ready**, and our **SATM** will be **complete**.
- We will have our first set of **architectures ready** for assessment
- In parallel, we will continue refining **metrics for** including **commercial** and partner **capability**, which will likely include multipliers such as:
  - Probability that a given capability will be available
  - Probability that NASA tasking will be given priority
  - Cost of data



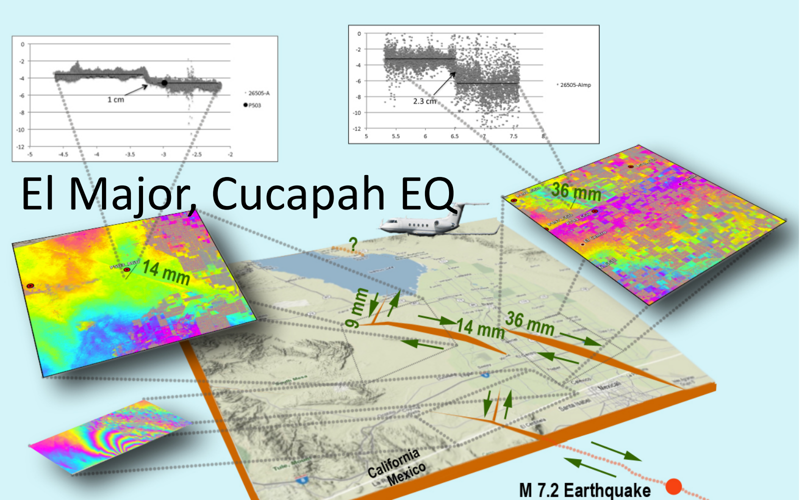
Note: Graphic of DLR's Tandem-L used to represent wide-swath future systems
Note: Graphic of ASI's CSK used to represent (relatively) small SAT SAR systems

Airborne SAR Also Under Consideration for SDC Science

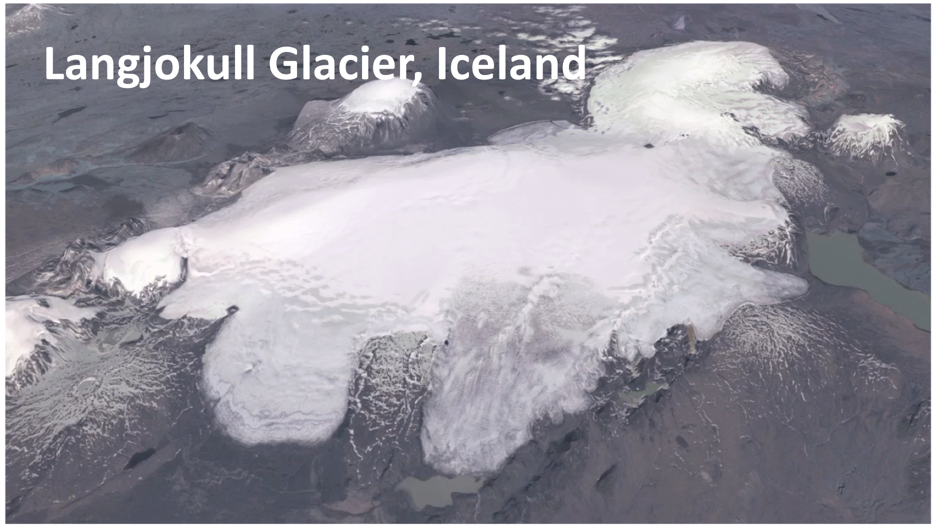
- Arbitrary view geometries (not fixed to a particular orbit)
- Multi-frequency, multi-polarization, multi-interferometry, multi-statics (think AIRSAR c. 1980-2000)
- Fast revisit – in the time it takes to loop around to repeat a flight track
- Cost-effective, high performance – UAVSAR has -50 dB NES0!
  - Opportunities for low-cost instrumentation with more modest performance, additional synergistic instruments
- Cost-effective on-board processing for near-real-time latencies



Credit: Cathleen Jones (JPL)



Donnellan, et al, 2014
Geochemistry, Geophysics, Geosystems



Airborne systems can provide measurements that are challenging to acquire from space

2016 and 2018 SNWG Inputs Go Beyond NISAR (and Probably SDC)

- As shown in an earlier presentation, inputs to 2016 and 2018 SNWG needs assessments are a challenge for any space-based observing system
  - Fine spatial resolution, down to ~ 1 m
  - Fast temporal sampling, down to hours
  - Low latency, down to hours
- SDC Science and Applications requested capabilities are similarly demanding
- The SDC team is adopting a system of systems approach in architectures to evaluate them in the science value framework
- SNWG SATM-like inputs can help guide the range of architectures considered
  - Flow-down from a specific problem statement to a specific measurement, preferably with an assessment of a lower limit or threshold on utility

Summary

- The Surface Deformation and Change Architecture Study will define NASA's SAR-based observing program for the post NISAR era
- SNWG needs overlap substantially with SDC desired capabilities
- The SDC team could take SNWG needs into account in the science value assessment if the needs can be mapped into an SATM-like structure.

- The second day of this workshop will go into greater detail on the elements of the SDC architecture study and allow for discussions of ways to incorporate SNWG inputs