SURFACE DEFORMATION AND CHANGE

National Aeronautics and
Space Administration

NASA

EARTH SYSTEM OBSERVATORY

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This is an animation

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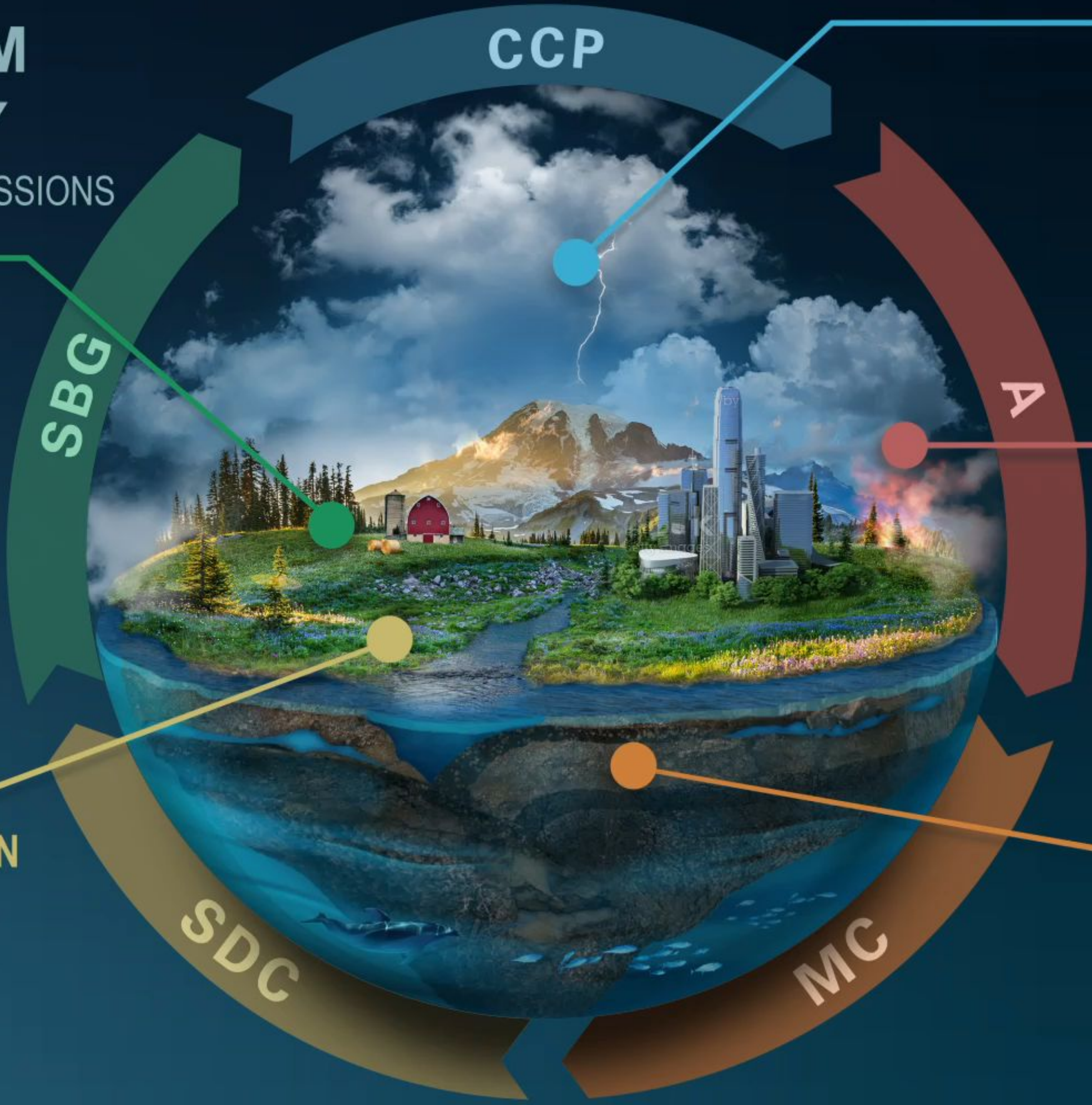
INTERCONNECTED CORE MISSIONS



CLOUDS, CONVECTION AND PRECIPITATION

Water and Energy in the Atmosphere

SURFACE BIOLOGY AND GEOLOGY

Earth Surface and Ecosystems

AEROSOLS

Particles in the Atmosphere

SURFACE DEFORMATION AND CHANGE

Earth Surface Dynamics

MASS CHANGE

Large-scale Mass Redistribution

Five things to know about the ESO

Before the end of this decade, NASA will put into orbit the Earth System Observatory (ESO)

The ESO is the heart of our implementation strategy for the Decadal Survey, addressing the most pressing questions about our changing planet posed by the Earth Science community through the National Academies' Decadal process

A single observation system comprised of 5 core satellite missions and 3 Earth Explorer missions

The ESO builds on the capabilities of NASA's 23 operating missions and the 18 in development that make up the program of record

NISAR serves as a "trailblazer" for the ESO, addressing one of the five core observables, involving substantial international partnership, advancing open-source science, and strongly coupling research and applied sciences

Surface Deformation and Change – SDC Mission Architecture Study

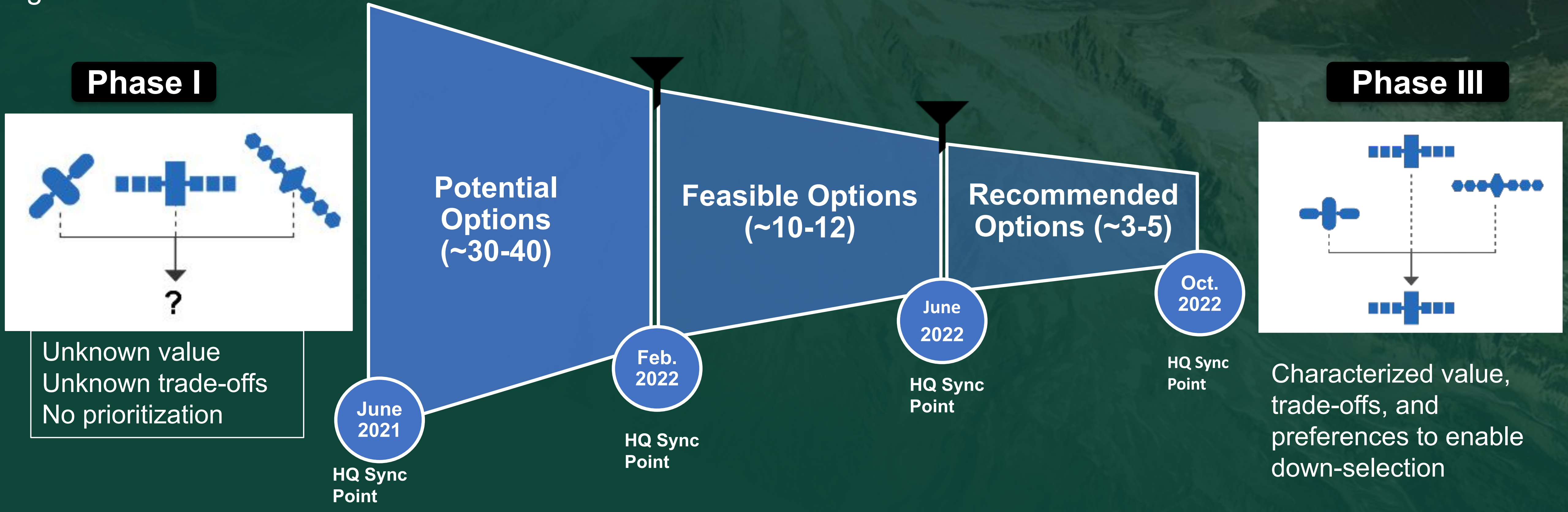
ESO will being with NISAR with SDC to follow.

SDC will consider the entire “program of record”, which includes data beyond its own system, but any SAR data that that is likewise free and openly available to the public. Such examples include:

- International SAR Constellations
- Commercial Data Purchased for Public Release

It is anticipated that partnerships will be needed to fully realize the vision described in the Decadal Survey.

A Value Framework is an **integrated value assessment of alternatives** which can be applied to concepts in pre-formulation. It is a collection of analytical methods and adaptable tools that characterizes the value of options, examines all elements of the decision space to understand trade-offs, and enables the down-select of preferred high-value solutions.



VALUE

Science Benefit	Architecture's ability to meet SATM targets for each Geophysical Observable
Application Benefit	Architecture's ability to support Enabled Applications and Application Communities
Programmatic Factors	Other benefits contributing to value (e.g. cross-benefit with other missions)
Cost	Architecture's total cost, including reserves
Risk	Programmatic and technical risks associated with the architecture

For each architecture

- The assessment is performed consistently
- Objective assessments are prioritized
- Checks and balances are implemented
- All data sources are archived and linked to summary products

Across all architectures

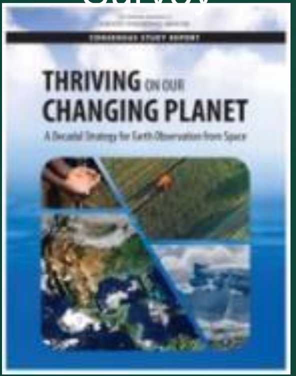
- The components of value are not aggregated into a single score to avoid:
  - Losing discriminators across architectures
  - Combining uncertainty and different levels of fidelity in the assessments
  - Anchoring cognitively on an initial value when the design process is iterative

Provides weighting and/or priority of the measured science

How well the science is measured

Per GO **Importance** to achieving Goals in Decadal Survey x **Necessity** to Objectives in the SATM x **Feasibility** of meeting measurement targets in the SATM = **Science Benefit**

Architecture's ability to meet SATM targets for each Geophysical Observable



From Decadal Survey

From Focus Groups

From <u>Performance Tool</u> and <u>Expert Consensus</u>

Quantifies architecture's revisit time, accuracy, coverage, and spatial resolution for Observables

Consensus assessment of likelihood of architecture's capabilities to satisfy SATM targets

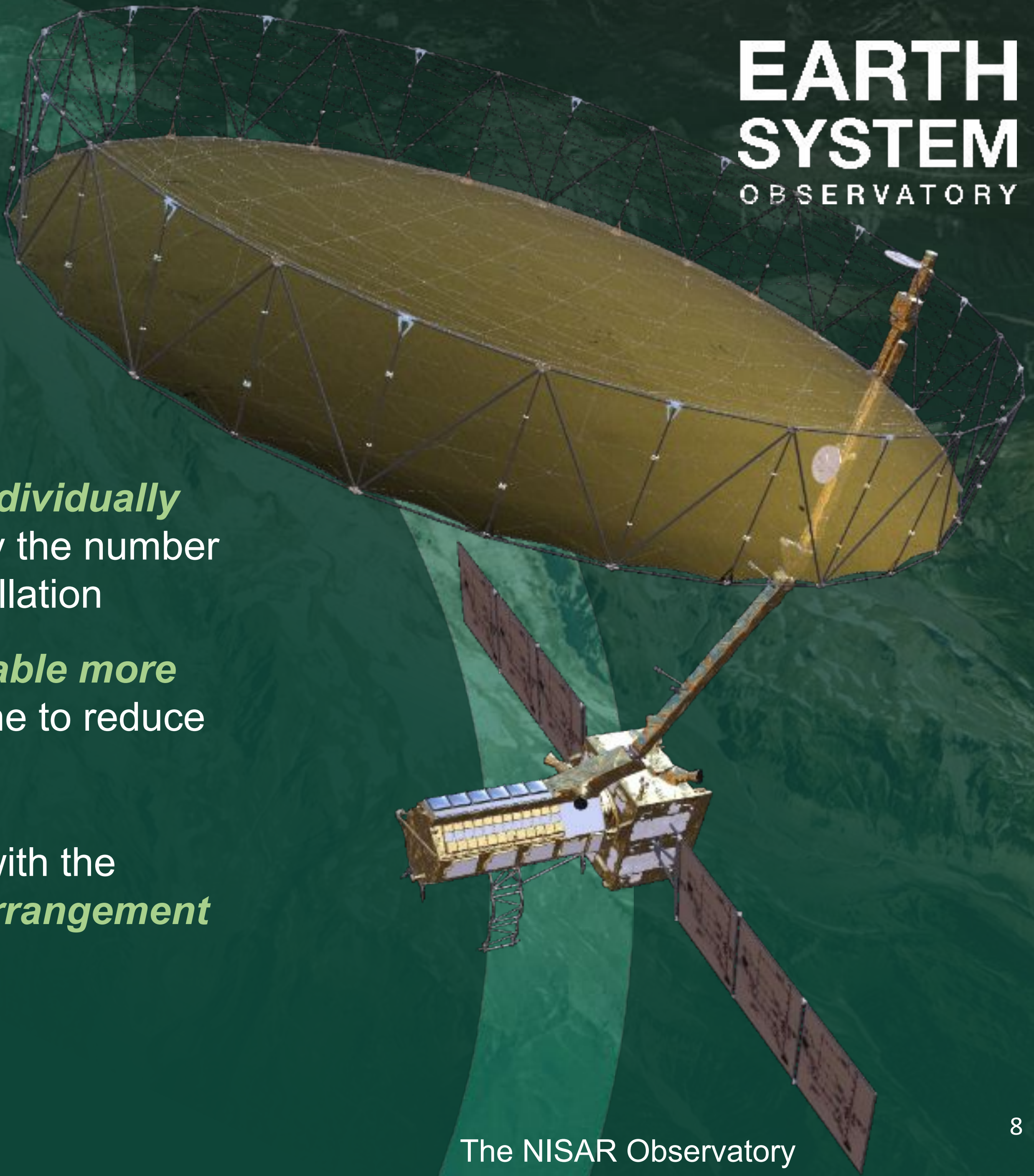
Architecture-agnostic

Per architecture

The <u>Performance Tool</u> quantitatively assesses the instrument performance with respect to target sets associated with the Observables. Where the Performance Tool is not available, a panel of <u>Expert Consensus</u> assessed the architecture's ability to satisfy the Observable targets in the SATM.

Architecture Concepts

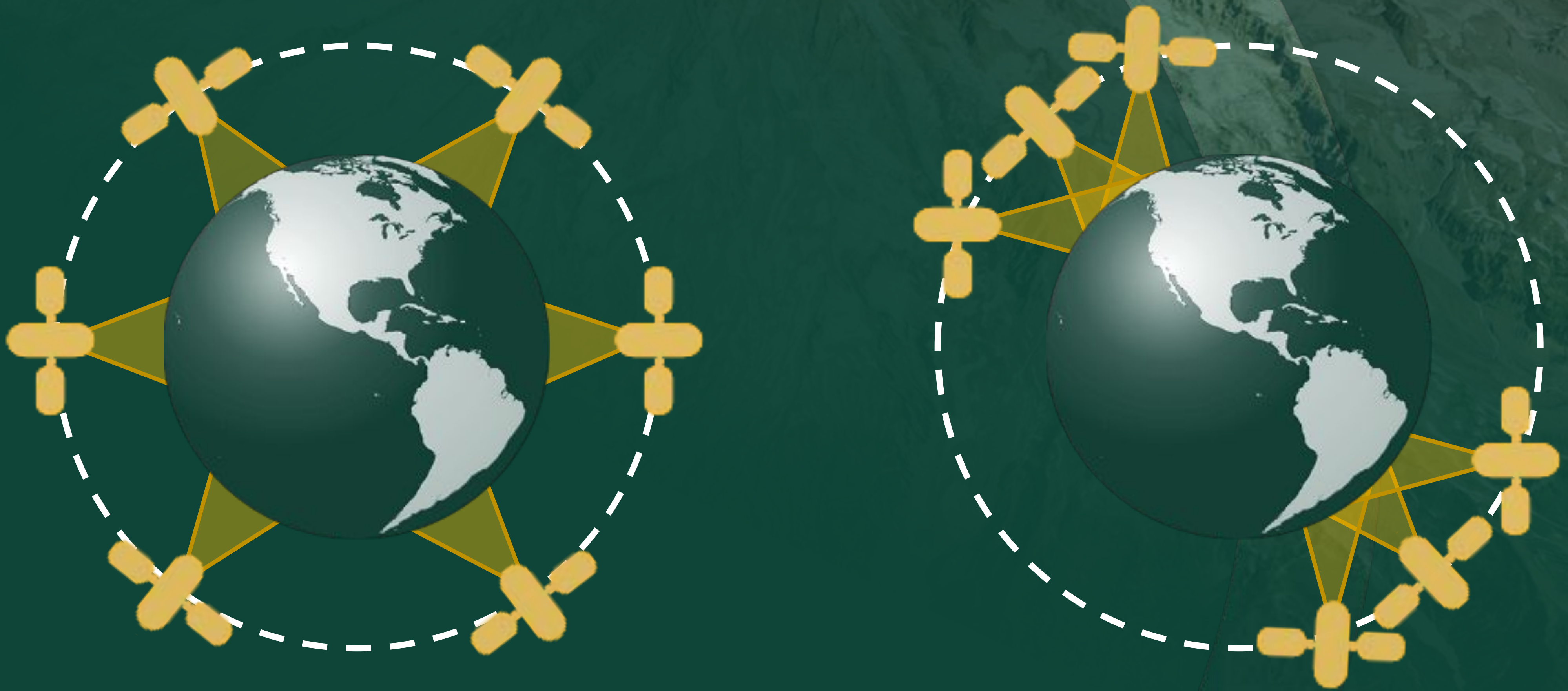
- Costs are proportional to coverage rate
  - Smaller satellites may be ***cheaper individually*** but those ***savings are given back*** by the number of satellites needed for the full constellation
  - We will utilize smaller satellites to ***enable more capability*** but do not expect that alone to reduce total mission cost
- Many of the instruments are very similar with the ***differences coming from their orbital arrangement***



The NISAR Observatory

Satellite Orbital Configurations

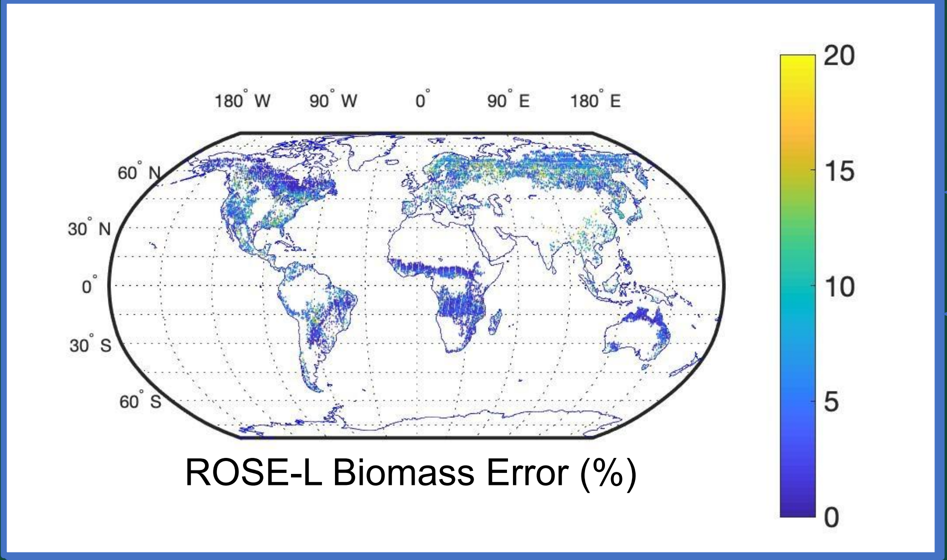
- Utilize a single orbital plane to maximize interferometric revisit opportunities
- Equal distribution around the plane increases revisit rate
- Formations of three enables estimation of three components of deformation and tropospheric delay



Architecture capabilities under exploration for SDC

The following capabilities would address the needs identified in the SATM:

- Fast revisit time globally
- Fast revisit time locally
- Reduced atmospheric error
- Estimation of surface topography and vegetation structure
- Good north-south vector deformation estimation



Performance Tool

Performance Tool

SATM Metrics

- **Revisit Time**
  - Interferometric revisit time
  - Imagery revisit time
- **Coverage <----> Accuracy**
- **Frequency Band**
- **Spatial Resolution**
- **Polarization**
- **Estimating Surface Topography and Vegetation Structure**

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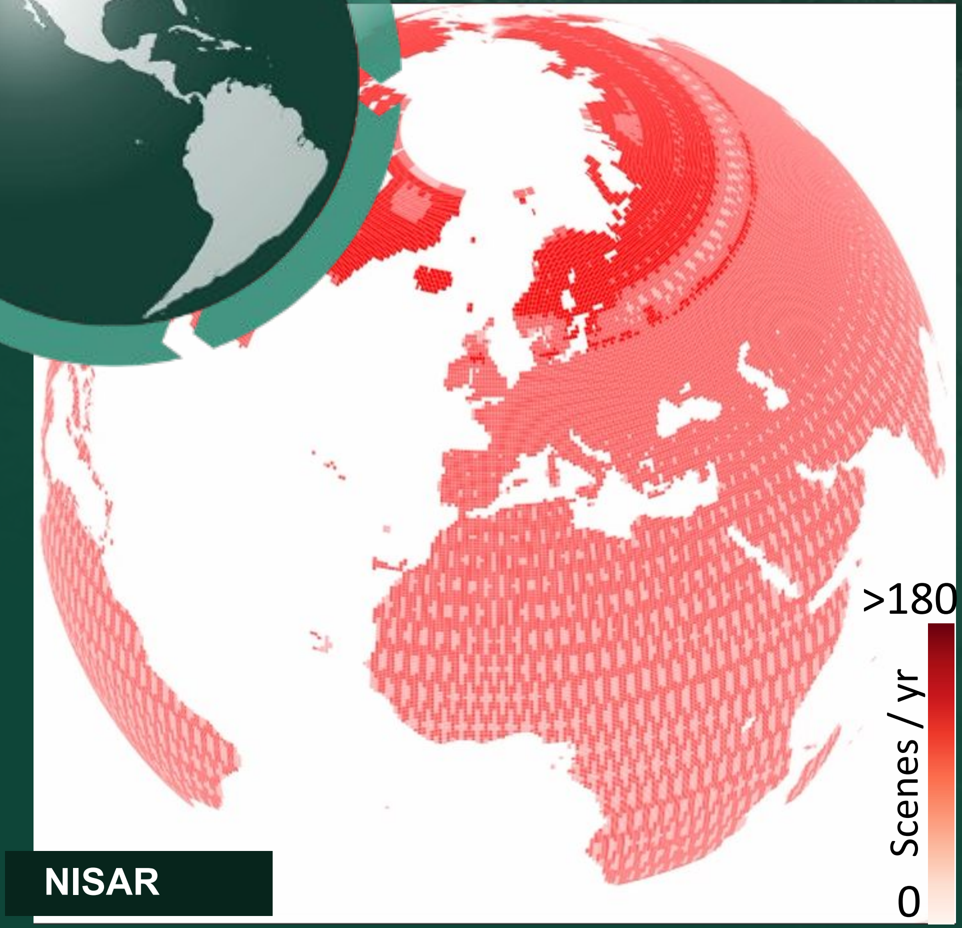

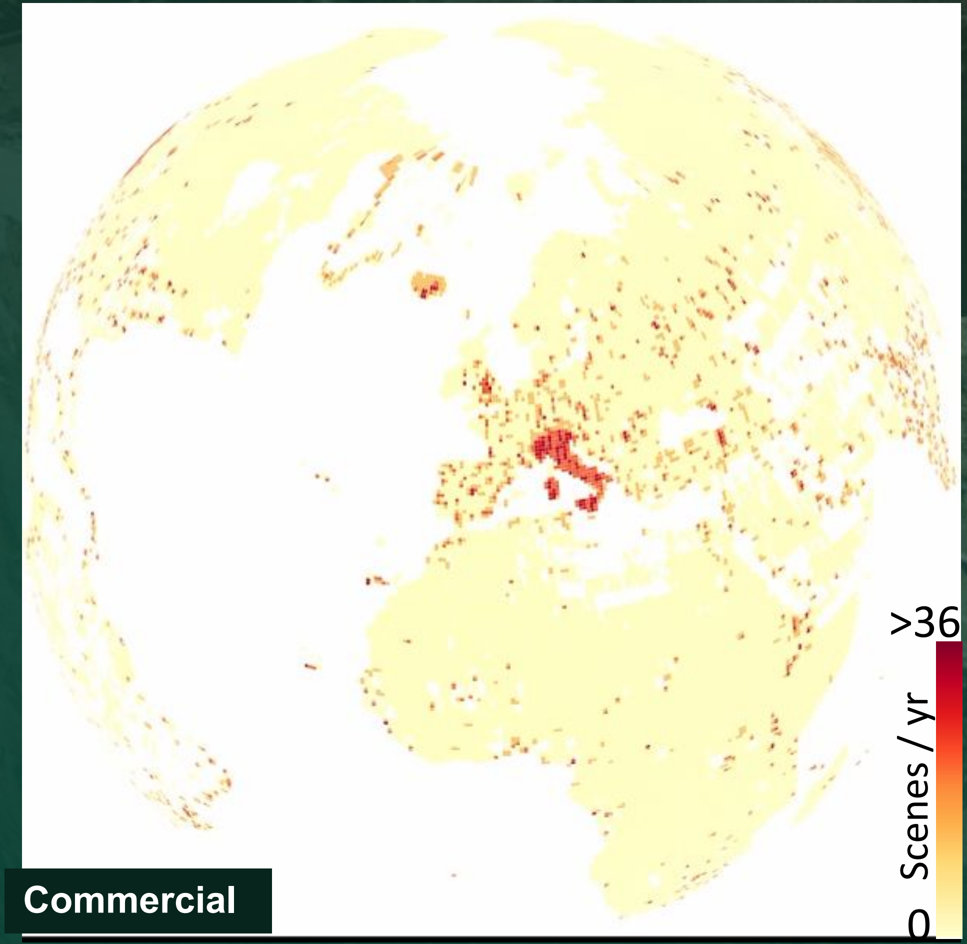

Coverage and Resolution SDC is planning to leverage the commercial SAR capabilities as much as possible to increase science return. There are also differences between SDC goals and perceived interests of commercial SAR companies, namely coverage and resolution. SDC aims to cover all global land masses uniformly, while commercial SAR data is available in areas of interest at high resolution. SDC commercial solution needs to be cost competitive with NASA systems which provide imagery at a few cents per sqkm.

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- Budget: $500M
- L- or S-band
- Full and open data
- Sharing the risk and expense
- Not a mission proposal, but a credible roadmap

We seek information on:

- Capabilities to provide the hardware
- Ability to avoid delays and cost growth
- Relevant experience and past performance
- Cost to NASA
- Willingness to enter PPP

SDC

"We're really excited to see NASA expand their outreach to commercial industry for their mission needs, and Capella is well suited to support this and other NASA requirements."
-Payam Banazadeh, CEO, Capella Space

"We admire and support NASA's long standing approach to leveraging public-private partnerships that enable the Government to take advantage of significant commercial innovations which benefit Earth Science missions."
- Eric Jensen, President, ICEYE USA

"We believe the best value to the government is always in allowing willing commercial companies to take on development risk and enter into long term data buy agreements."
-Todd Master, COO, Umbra

"Terran Orbital applauds NASA's consideration of commercial capabilities to meet mission needs. By leveraging commercial investments in space-based remote-sensing and processing architectures, they will be able to focus limited resources executing critical science missions rather than developing point solutions to collect data."
-Marc Bell, CEO, Terran Orbital

Industry

Request For Information (RFI) We have released an RFI to solicit information from the commercial SAR industry can help to make the most out of the SDC mission.

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Community Inputs Refined our SATM

Science Question or Societal Goal	*Science or Application Objective*	*Science or Application Importance*
Geophysical Observable **Most Important | Very Important | Important**		
Measurement Parameters		
Temporal	***Spatial***	***Observation***
Product Generation Frequency Daily | Weekly | Monthly | Annual	Horizontal Resolution 10m | 50m | 100m | 1km	Wavelength C- | S- | L- | Any Band
Temporal Sampling Needs Daily | Weekly | Monthly	Horizontal Deformation Accuracy cm/yr | m/yr	Polarization Co- | Cross- | Quad-Pol
Latency Hours | Days | Months	Elevation Accuracy m	Radiometric Accuracy dB
Temporal Continuity Months | Years | Decades	Vertical Deformation Accuracy mm/week | mm/year	Phase Accuracy deg
	Geocoding Accuracy m	Interferometric Baselines m
	Coverage Site Specific | Global Land	

Decadal Survey Inputs

Your Feedback

Workshops
Focus Groups
Industry Engagement
Conferences

Enabled Applications

Application Communities
Community Assessments

Value Framework

Performance Simulation
Objective Scoring

Architecture Assessment

The ***SDC Science and Applications Traceability Matrix*** summarizes our desired geophysical observables, their importance, and enabled applications to inform architecture evaluations.

Solid Earth and Geohazards

- Solid Earth and Geohazards express similar needs for routine observations but with stronger latency needs when responding to a disaster.

- In the SATM, we capture these differences.
    - For example:

Earthquakes	Solid Earth	Geohazard
Coverage	Global Access	Localized
Revisit	Daily	Daily
Resolution	10 m near fault to 50 m	10-30 m
Data Latency	Not Prioritized	< 3 hours (coseismic) < 12 hours (postseismic)

- Both desire L- and/or S-band observations to maximize coherence and reduce impacts from vegetation

- Commercial data buys may complement an SDC architecture to address specific Geohazards needs.

Cryosphere

- Land Ice:
    - High accuracy (10m/yr + 1%) and sustained observations of coastal glacier ice is of highest priority, **achievable by the Program of Record.**
    - This may allow SDC to focus on advancements in spatial and temporal improvements.
- Sea Ice:
    - Carefully negotiating tradeoffs between spatial resolution, temporal resolution, and coverage
    - Challenging, because:
        - Circumpolar, fine resolution mapping of sea ice motion is of high priority
        - A strong priority on high-temporal sampling (4-6 times daily) in combination with fine spatial resolution.
        - However,

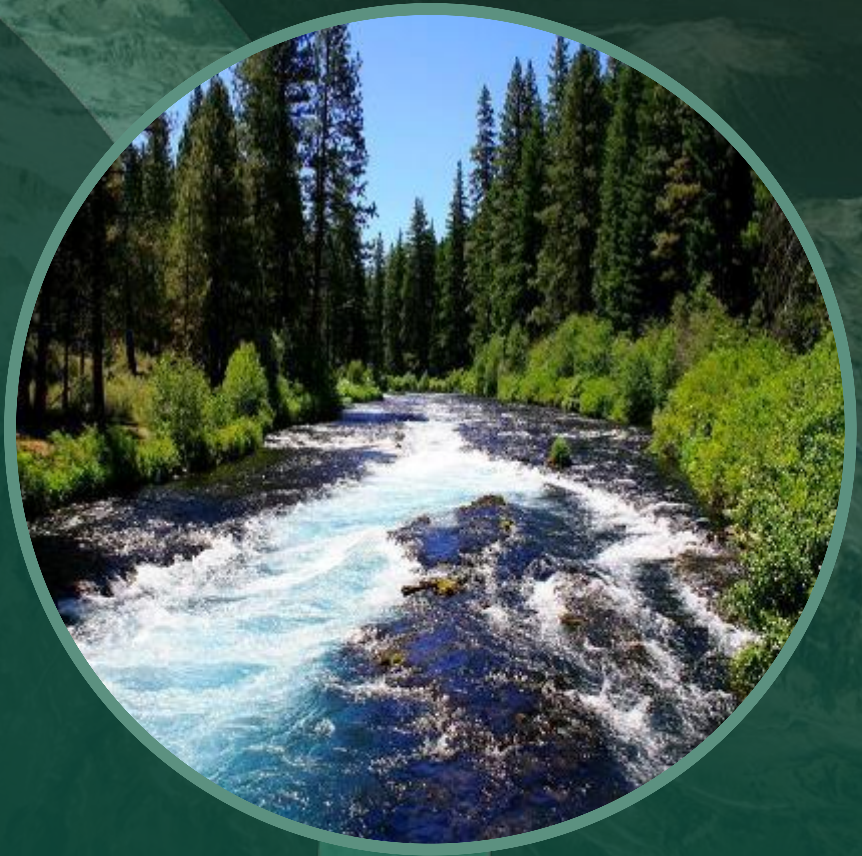
          Significant science could be achieved with targeted (in space and time) seasonal campaigns.

Hydrology

- The SATM includes 6 focus areas for Hydrology across 8 geophysical observables.

- Groundwater
  - Slower-changing, where continuity of long-term record is critical
- Soil Moisture
  - Evolves quickly, where moderate temporal and higher spatial resolution is desired
- Surface Water Extent
  - Includes disaster response (floods), desiring high spatial and temporal resolution

Water Extent	Hydrology	Geohazard
Coverage	Global Access	Localized
Revisit	Daily	< 4 hours; 6+ hour (recovery)
Resolution	10 m	10 m; 3 m preferred
Data Latency	Not Prioritized	< 2 hours (crisis) > 2 hours (recovery)



Ecosystems

- The SDC R&A team convened workshops and focus groups to create an SATM, complementing the original Decadal Survey.

  - Emphasized areas include
    - Soil Moisture (absolute and relative)
    - Biomass and biomass change
    - Agricultural management
    - Wetlands

- 10 new science focus areas and geophysical observables were added to the SATM:, desiring:
  - Continuity with NISAR but with increased temporal resolution – extend the period of observations
  - Global coverage over land surfaces

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Community Assessment Report

Applications Informing Architecture Selections

Engagement with the community ensures that information gathered informs our decision-making process:

- ***26 enabled application areas*** were derived from our SATM and Geophysical Observables.
- ***12 application communities*** were created and inclusive of public and private needs, to be detailed in a final report.
- The ***value framework process*** incorporates specific application needs in assessments
- Applications help inform our ***down-selection to 12 potential architectures*** in 2022.

Decadal Survey Inputs

↓

Your Feedback

↓ Workshops
Focus Groups
Industry Engagement
Conferences

Enabled Applications

↓ Application Communities
Community Assessments

Value Framework

↓ Performance Simulation
Objective Scoring

Architecture Assessment

Community Assessment Report

New, Early Consideration of Mission Applications

RTI Innovation Advisors conducted targeted interviews with individuals at for-profit and non-profit organizations emphasizing future applications in the SDC era.

Lessons Learned

- Public and private sector entities will explore SAR when it is a proven advantage
- Technical knowledge, access to data, and processing tools supporting value-added products are needed to advance use of SAR in many communities

Potential Solutions

- NASA will provide free and open access to NISAR, SDC, and other data
- NASA's Open Science initiatives will ensure equitable access to data processing tools, availability of products within cloud environments,
- Open Science collaborations will generate value-added analyses from SAR data

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Keep Engaging with our SDC Study!

- Visit our SDC Study Team Webpage:
  - https://science.nasa.gov/earth-science/decadal-sdc

- Join the SDC email list for updates
  - Send an email to SDC-Community-join@lists.nasa.gov
  - You do not have to put anything in the subject line or the body.
  - Follow the instructions in the email to confirm.

- Keep updated on our 2022 activities, which include:
  - Synthesizing community inputs and releasing an updated version of our SATM
  - Down-selection to 12 architectures mindful of science and application goals
  - Completing and sharing our Community Assessment Report

- Please review our SATM, your discipline area, and reflect on the science goals.
  - ***Our charge to you: let us hear your feedback on the SATM!***

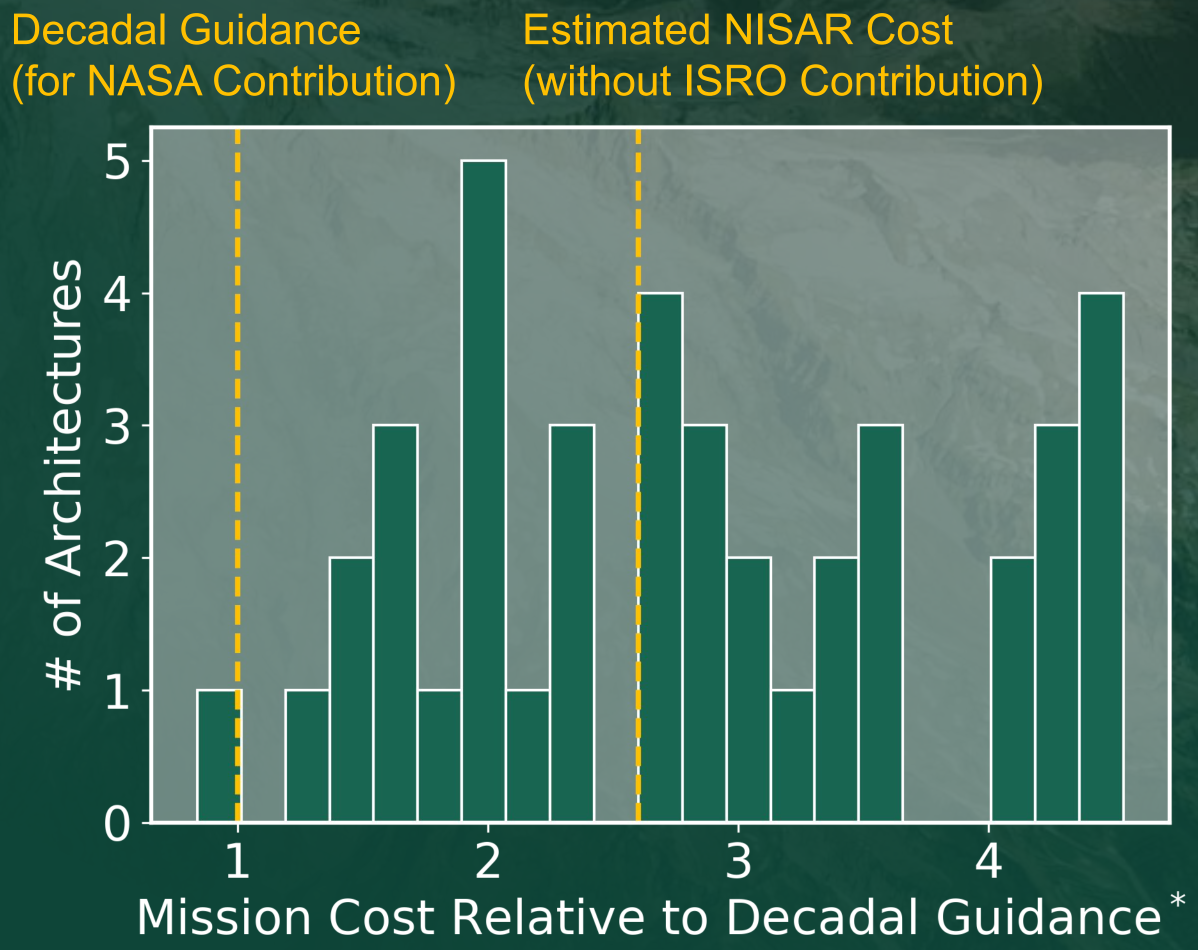
SATM

SATM Feedback

Backup slides

Partnerships are Critical to SDC

- Analogy-based historical cost estimation for SDC architecture concepts shows nearly all come out ***over the recommended threshold*** from the decadal survey
- SDC must ***utilize partnerships and other creative acquisition strategies*** in order to align the SATM objectives to the available funding.

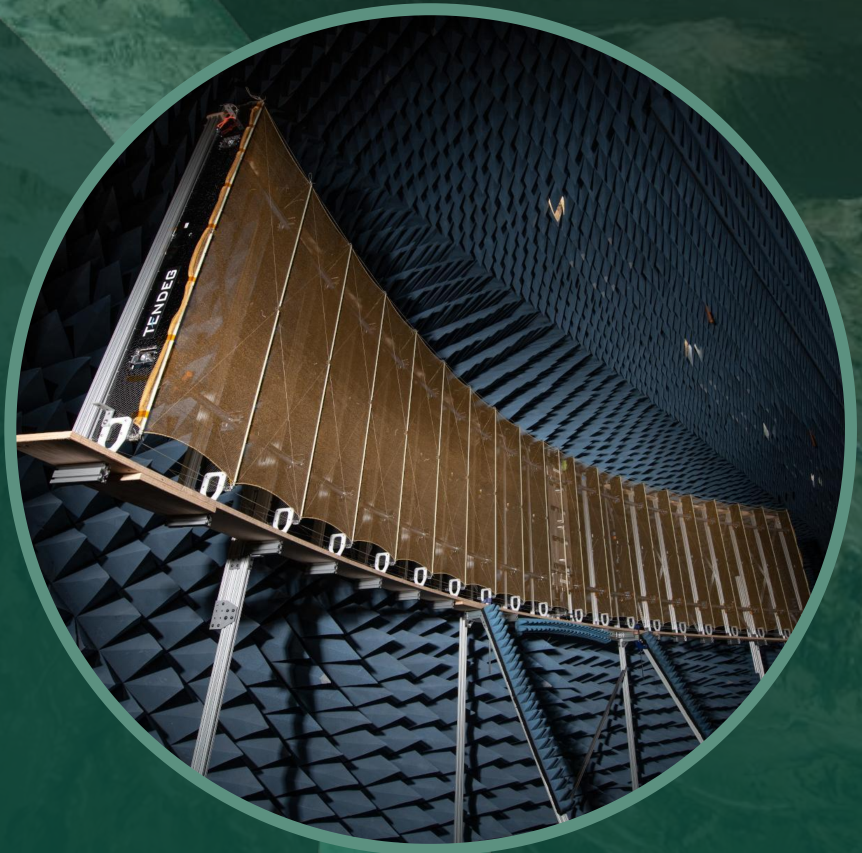


* Cost estimation is for phase A-F and includes reserves. Assumes entirety of cost is borne by NASA using past analogy costs

Technology Investment

Focus on key technology areas for instrument miniaturization in a global collection paradigm:

- Digital Electronics and Integration
- Antenna Apertures
- Thermal Transport



7.5 x 1.5 m2 mesh aperture technology demonstration

Fast Global Revisit Time (L4A)

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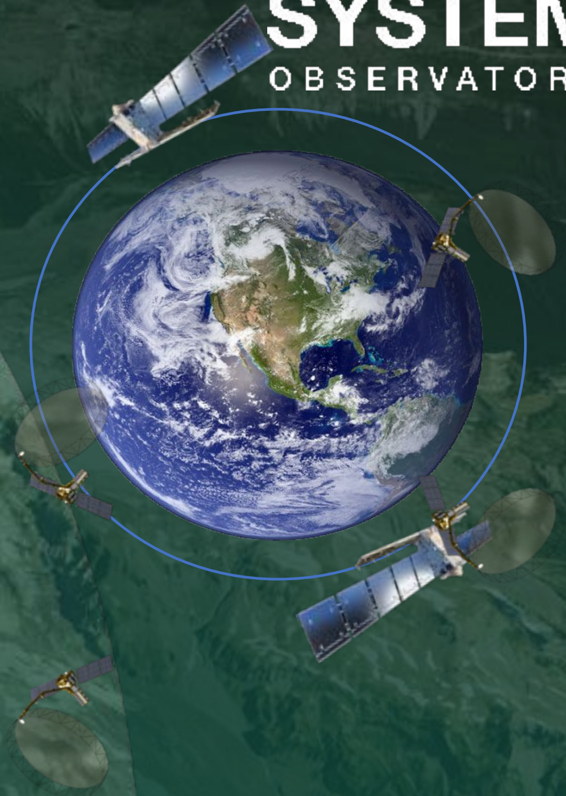
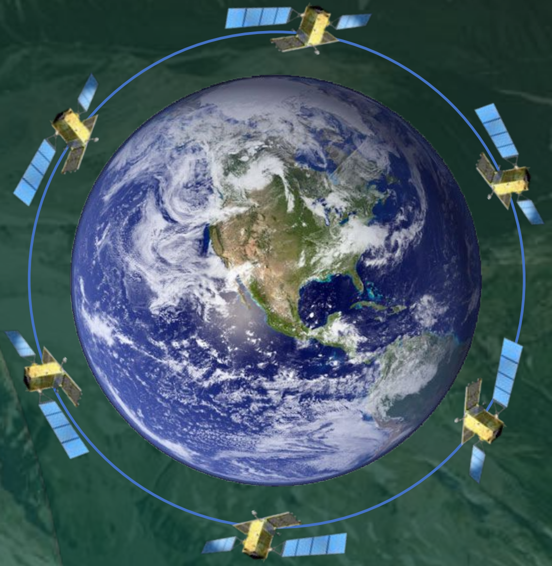


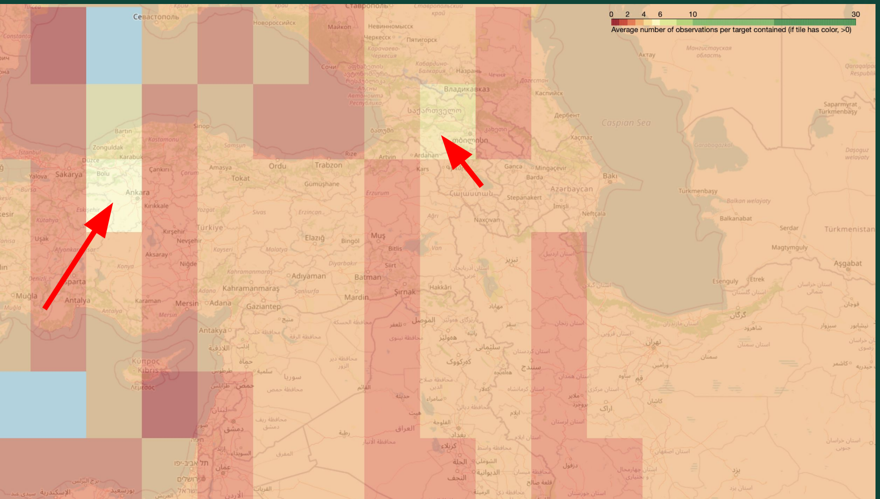
- L4A: 2 NISAR-lite and ROSE-L
- 4 days revisit time globally
- Lower duty cycle due to overlaps in higher latitudes

	Revisit Time	Accuracy	Revisit Time (NISAR)	Accuracy
Above ground vegetation biomass & biomass change	2 days	4.6 Mg/ha	6 days	8.1 Mg/ha
Earthquake Cycle and Hazards, Land surface deformation	3 days	1.2 mm	12 days	2.04 mm

Fast Urgent Response Revisit time (L6A)

- 6 satellites with 1/6 NISAR swath
- 2 days revisit time for urgent response
  - Longer revisit time for urgent response neighbors

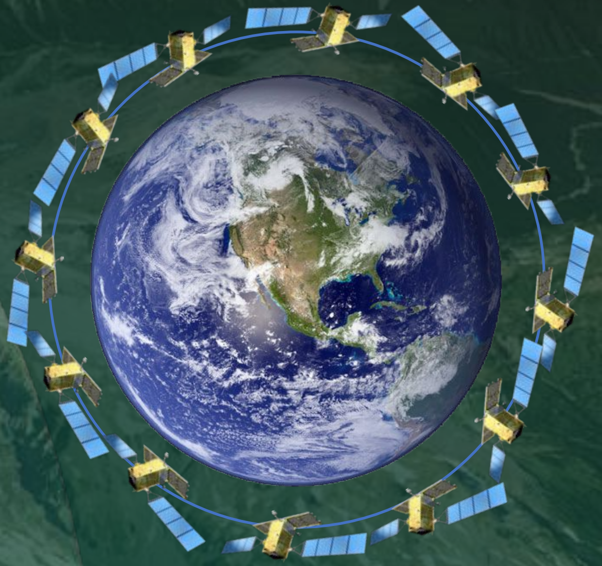


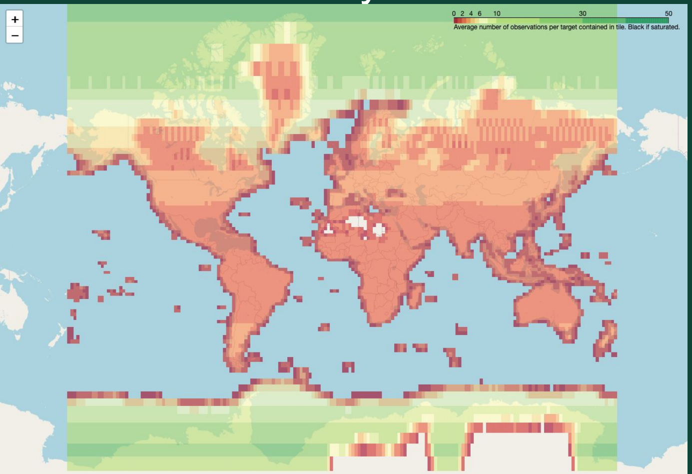


	Revisit Time (L6A)	Accuracy (L6A)	Revisit Time (NISAR)	Accuracy (NISAR)
Volcanic Systems and	2 days	0.85 mm	12 days	2.04 mm

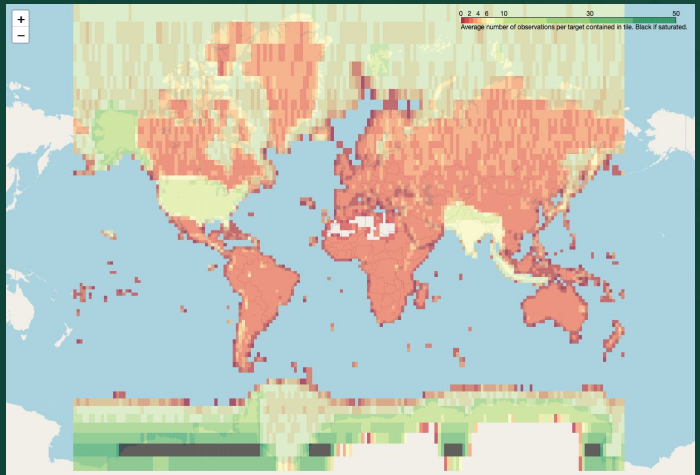
Fast Local Revisit time

- 12 satellites with ¼ NISAR swath
- low NES0 (-15dB)
  - not useful for some application such as soil moisture and biomass estimation.
- low duty cycle (15% compare to 50% NISAR)
- 1 days revisit time for urgent response
- systematic faster revisit time over a region such as US/Alaska with minimum observation needed everywhere else





NISAR Revisit



12 1/4 swath NISAR Revisit

	Revisit Time (L6A)	Accuracy (L6A)	Revisit Time (NISAR)	Accuracy (NISAR)

SDC Research and Applications (R&A) Team

Activities and Accomplishments

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- We completed Version 1 of the ***Science and Applications Traceability Matrix (SATM)***
  - The SATM was released on the SDC website and is open for community comments.
- We focused on ***new opportunities to engage with industry*** to capture their SDC needs
  - RTI Innovation Advisors conducted interviews with our guidance and collaboration. Their resulting report, available online, tells us how SDC will support future needs of industry.
  - We are exploring how current and future ***commercial SAR data*** can complement SDC.
- We began writing our ***Community Assessment Report (CAR)*** on SDC's applications potential.
  - The CAR will help guide SDC in its future engagements with various end users.
  - Input from RTI, previous NISAR Applications efforts, and other NASA engagements (Satellite Needs Working Group, Applied Science/Early Adopters, etc.) will be assessed during the CAR development for a holistic view SAR communities of practice and potential.
- Our team has been exploring of potential ***partnerships with philanthropies and foundations***.
  - SDC may benefit through their investments in foundational science, new applications, and workforce development through grants and other activities.

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