Surface Topography and Vegetation
(STV) Incubation Study

Fall 2020 AGU Town Hall

Andrea Donnellan, STV Study Lead
NASA, Jet Propulsion Laboratory, California Institute of Technology
Dave Harding, STV Technology Lead
NASA Goddard Space Flight Center
Bob Bauer and Ben Phillips
NASA Headquarters

2020 AGU STV Town Hall Agenda (PST)

- 7:00 Welcome
- 7:05 NASA HQ Perspective — Bob Bauer, Ben Phillips
- 7:15 Science and Applications — Andrea Donnellan
- 7:30 Technologies — David Harding
- 7:45 Discussion — Team and audience
- 8:00 Adjourn

Q&A Link: https://arc.cnf.io/sessions/qkrg/#!/dashboard
STV Webpage: https://science.nasa.gov/earth-science/decadal-stv/

Ground Rules

- Only material suitable for full and open distribution shall be submitted
  - Submittals shall be considered approved by the providing organization to be suitable for full and open distribution
  - No proprietary, export controlled, classified, or sensitive material should be provided

- **Q&A:** https://arc.cnf.io/sessions/qkrg/#!/dashboard

Decadal Survey Incubation (DSI) Overview

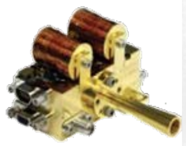
Ben Phillips, Bob Bauer, NASA Headquarters

Earth Science Technology Program Elements

ESTO manages, on average, 120 active technology development projects. Over 830 projects have completed since 1998.

Advanced Technology Initiatives Program (ATIP)

Advanced Component Technologies (ACT)



Critical components and subsystems for advanced instruments and observing systems

Selections pending for ACT-20.
Solicitations planned in FY22 *and FY24*
Average award: $1.2M (2-3 years)
Average selection rate: 16.4%

In-Space Validation of Earth Science Technologies (InVEST)

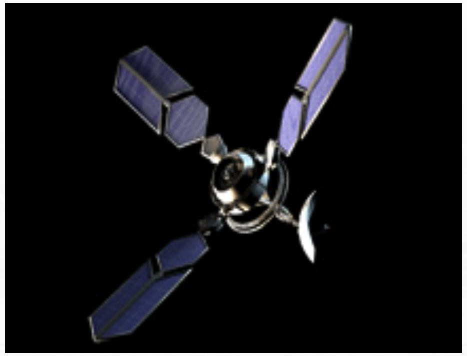
On-orbit technology validation and risk reduction for small instruments and instrument systems.

Four projects selected in FY18. ***InVEST-20 release is imminent. Solicitations planned in FY24 and FY27***
Average award: $3-5M (3 years)
Average selection rate: 18.3%

Instrument Incubator Program (IIP)

Earth remote sensing instrument development from concept through breadboard and demonstration

19 projects awarded in Oct 2019
Solicitations planned in FY21 and FY23
Average award: $4.5M (3 years)
Average selection rate: 23.2%



Advanced Information Systems Technology (AIST)

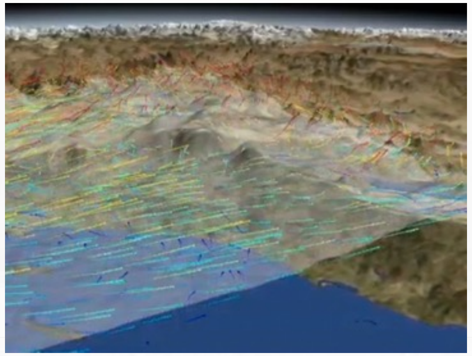
Innovative on-orbit and ground capabilities for communication, processing, and management of remotely sensed data and the efficient generation of data products

22 projects awarded in Sept 2019
Solicitations planned in FY21 and FY23
Average award: $1.2M (2 years)
Average selection rate: 19.6%

Decadal Survey Incubation (DSI)

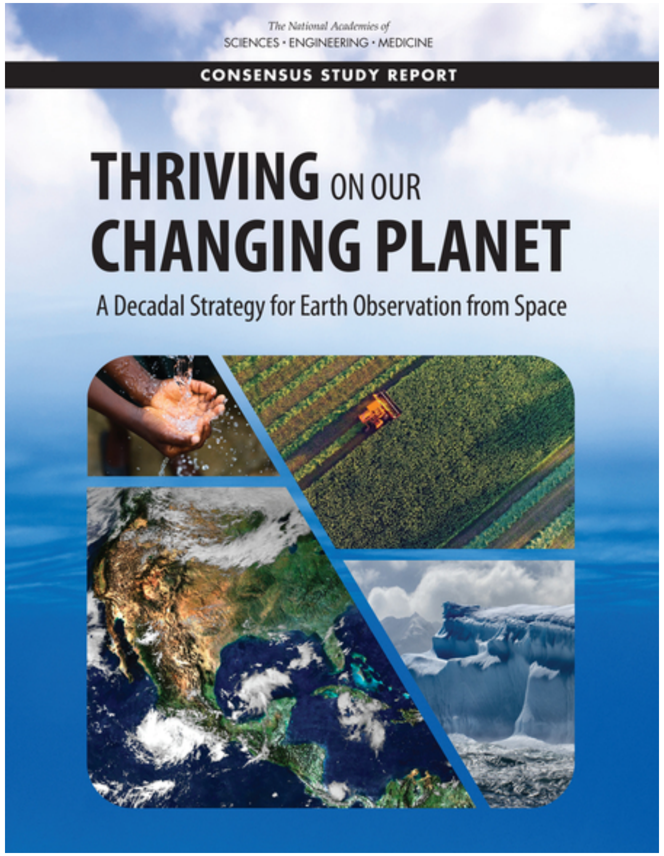
Maturation of observing systems, instrument technology, and measurement concepts for Planetary Boundary Layer and Surface Topography and Vegetation observables through technology development, modeling/system design, analysis activities, and small-scale pilot demonstrations

2 Study teams awarded in FY20
Solicitation planned in FY21



Decadal Survey Incubation Program

- A new program element in the 2018 Decadal Survey, focused on investment for priority observation capabilities needing advancement prior to cost-effective implementation
- Two elements: Planetary Boundary Layer (PBL), and Surface Topography and Vegetation (STV)
- Supports maturation of mission, instrument, technology, and/or measurement concepts to address specific high priority science (for the following decade)
- Managed by ESTO and run as a partnership with R&A
- Anticipate a mix of activities:
  - Technology development activities
  - Modeling/system design and analysis activities
  - Small scale pilot demonstrations
  - Typically 1- to 3-year activities



Decadal Survey Incubation Overview/Plans

- A new program element in the 2017 Decadal Survey, focused on investments for priority observation capabilities needing advancement prior to cost-effective implementation
- Two elements: Planetary Boundary Layer (PBL), and Surface Topography and Vegetation (STV)
- Supports maturation of mission, instrument, technology, and/or measurement concepts to address specific high priority science (for 2027-2037 decade)
- Assigned to ESTO to manage, however, is run as a partnership between ESTO and R&A
- Funding profile ($M):

	FY20	FY21	FY22	FY23	FY24	FY25
Original FY 22	8.0	0.0	20.0	20.0	15.0	15.0
Proposed PPBE22	8.0	3.0	17.0	20.0	15.0	15.0

PLANS

- FY21 – complete Study Teams; continuation of augmented tasks (CS labor); release DSI ROSES-21 solicitation
- FY22 – Begin funding new ROSES awards; some directed work possible
- ROSES-21 DSI Solicitation (targeting release in late Spring)

  - Will use Study Team white papers to inform NASA in writing the call
  - Anticipate awards up to ~$1.5M/y for 3 years (although still TBD att)
  - # of awards TBD, as is split between STV and PBL

ESTO Upcoming Solicitations

	FY20	FY21	FY22	FY23	FY24	FY25	FY26
ACT	Q3		Q2		Q2		Q2
InVEST		Q1			Q1		
IIP		Q3		Q3		Q3	
AIST		Q3		Q4		Q4	
DSI		Q3			Q3		
SLI-T	Q2			Q1			Q1

Incubation Targeted Observables: Decadal Survey

TABLE S.2 Continued

Targeted Observable	Science/Applications Summary	Candidate Measurement Approach	Designated	Explorer	Incubation
Planetary Boundary Layer	*Diurnal 3D PBL thermodynamic properties and 2D PBL structure* to understand the impact of PBL processes on weather and air quality 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 and Vegetation	*High-resolution global topography*, including bare surface land topography, ice topography, vegetation structure, and shallow water bathymetry	Radar; or lidar*			X

National Academies of Sciences, Engineering, and Medicine 2018. Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space. Washington, DC: The National Academies Press. https://doi.org/10.17226/24938.

STV Incubation Trajectory

- **ROSES-2019,** A.54 DECADAL SURVEY INCUBATION STUDY TEAMS: PLANETARY BOUNDARY LAYER (PBL) AND SURFACE TOPOGRAPHY AND VEGETATION (STV)

  "…to identify methods and activities for improving the understanding of and advancing the maturity of the technologies applicable to these two TOs and their associated science and applications priorities."
- Nov. 2019 – Two study teams selected; one for PBL, one for STV
- Dec. 2019 – NASA Surface Topography and Vegetation Incubation Community Forum
- Mar. 2020 – Study Team work began
- Each team is to produce a white paper for delivery to NASA HQ in early CY21, that will help inform the next ROSES solicitation in FY21 and funding in FY22+
  - Outline potential future methods and activity areas, such as modeling and OSSEs; field campaigns; and a range of potential observing system architectures utilizing emerging sensor and information technologies
  - Other deliverables include a preliminary Science and Applications Traceability Matrix (SATM)
  - Each Study Team "*will solicit input from the broader scientific community*"

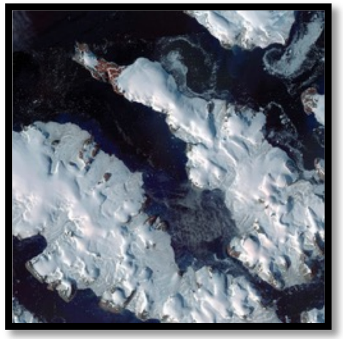
STV Incubation Study Objectives

- Decadal Survey: “A new program element called ‘Incubation,’ intended to accelerate readiness of high-priority observables *not yet feasible for cost-effective flight implementation*.”
- STV is not a mission or an observing system
- The STV Incubation Study is not a Designated Observables Study
- The STV Incubation Study is focused on:
  - State-of-the-Art Evaluation
  - Identification of Gaps and Investment Needs
  - Preliminary Requirements Refinement

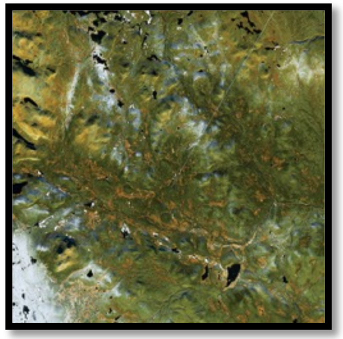
STV Science/ Applications

Bare-surface Topography

Ice Topography



Vegetation Structure



Shallow-water Bathymetry

Decadal Survey Incubation – HQ Points of Contact

Program Manager: Robert Bauer/ESTO, robert.bauer@nasa.gov

Topic	Program Scientist	Technology Lead
Surface Topography & Vegetation (STV)	Ben Phillips ben.phillips@nasa.gov	Bob Connerton robert.m.connerton@nasa.gov
	Along with: Hank Margolis hank.a.margolis@nasa.gov Thorsten Markus thorsten.markus@nasa.gov	

Surface Topography and Vegetation
(STV) Incubation Study

Study Overview and Science and Applications

Andrea Donnellan, STV Study Lead

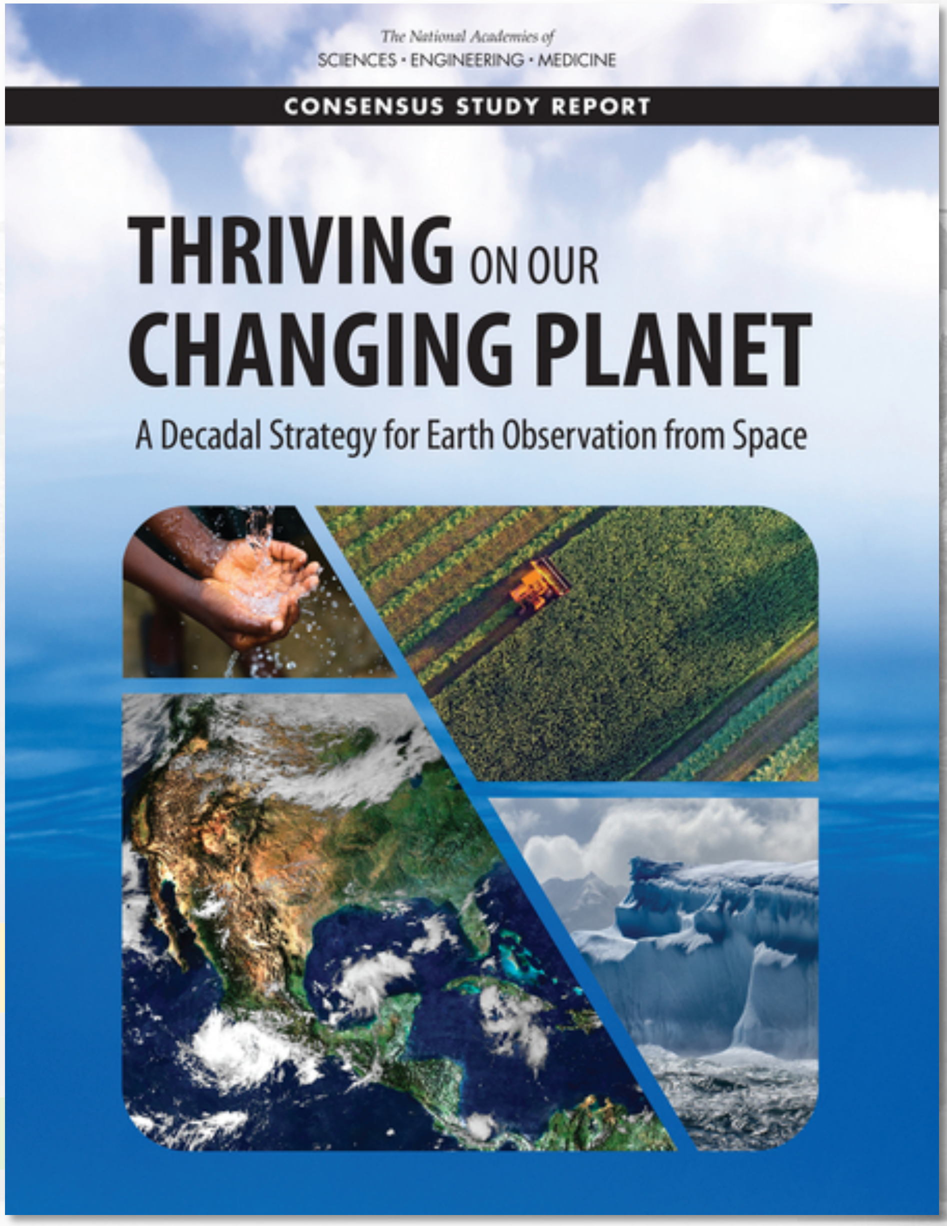
NASA, Jet Propulsion Laboratory, California Institute of Technology

Decadal Survey

- Targeted Observable:
  Surface Topography and Vegetation
- *High-resolution global topography*, including bare surface land topography, ice topography, vegetation structure, and shallow water bathymetry
- Candidate Measurement Approach:
  radar or lidar *[Stereo Photogrammetry]*

Solid Earth ***Ecosystems*** ***Climate*** ***Hydrology*** ***Weather***

Solid Earth ***Vegetation Structure*** ***Cryosphere*** ***Hydrology*** ***Coastal Processes***



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

STV Incubation

- **STV incubation:** seeks observing system architectures utilizing emerging sensors that will allow for the development of **contiguous, high-resolution, bare-surface land topography, ice topography, vegetation structure, and bathymetry** data products with ***global coverage and seasonal interannual repeat*** cycles.
- **Decadal Survey:** "topographic mapping from space on a **contiguous and high-resolution grid** poses a major technological challenge, it is a necessary and logical next step that promises to transform understanding of landscape evolution and the interactions of processes that shape them. ….. ***Space-based, global coverage remains an important but unrealized goal at present***."

Science Breakouts

Solid Earth
- Tectonics/deposition/erosion/climate coupled processes
- Earthquake, volcano and landslide assessment, response, mitigation and modeling
- Anthropogenic and natural change detection

Vegetation Structure
- Ecosystem structure and function
- Carbon accounting
- Biomass inventory, dynamics, monitoring
- Biodiversity, habitat structure and response to disturbance
- Forest resources management
- Wildfire, fuel, risk and post-fire recovery

Cryosphere
- Ice sheet, ice cap and glacier elevation change and sea level impact
- Sea ice thickness and cover change and impact on the ocean/atmosphere system
- Ice flow and dynamics
- Constraints for time-series modeling

Hydrology
- Lake and reservoir heights and shallow bathymetry
- Snow depth and melt impact on water resources
- Stream and river flow
- Flooding and inundation modeling
- Wetland processes and management

Coastal Processes
- Storm surge and tsunami inundation hazards
- Shoreline erosion and sediment transport
- Benthic habitat and marine ecosystems
- Tidal interaction with mangroves and salt marshes
- Shallow water navigation and hazards

Applications

Team Members

Lead

Andrea Donnellan

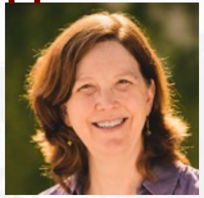
Tech Lead

Dave Harding

Cryosphere

Alex Gardner

Applications



Cathleen Jones

Marco Lavalle

Radar

Yunling Lou

Solid Earth

Paul Lundgren

Scott Luthcke

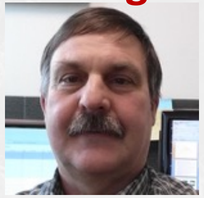
Information Systems

Batuhan Osmanoglu

Coastal Processes

Christopher Parrish

Stereo Photogrammetry



Jon Ranson

Sassan Saatchi

Hydrology

Marc Simard

Lidar

Jason Stoker

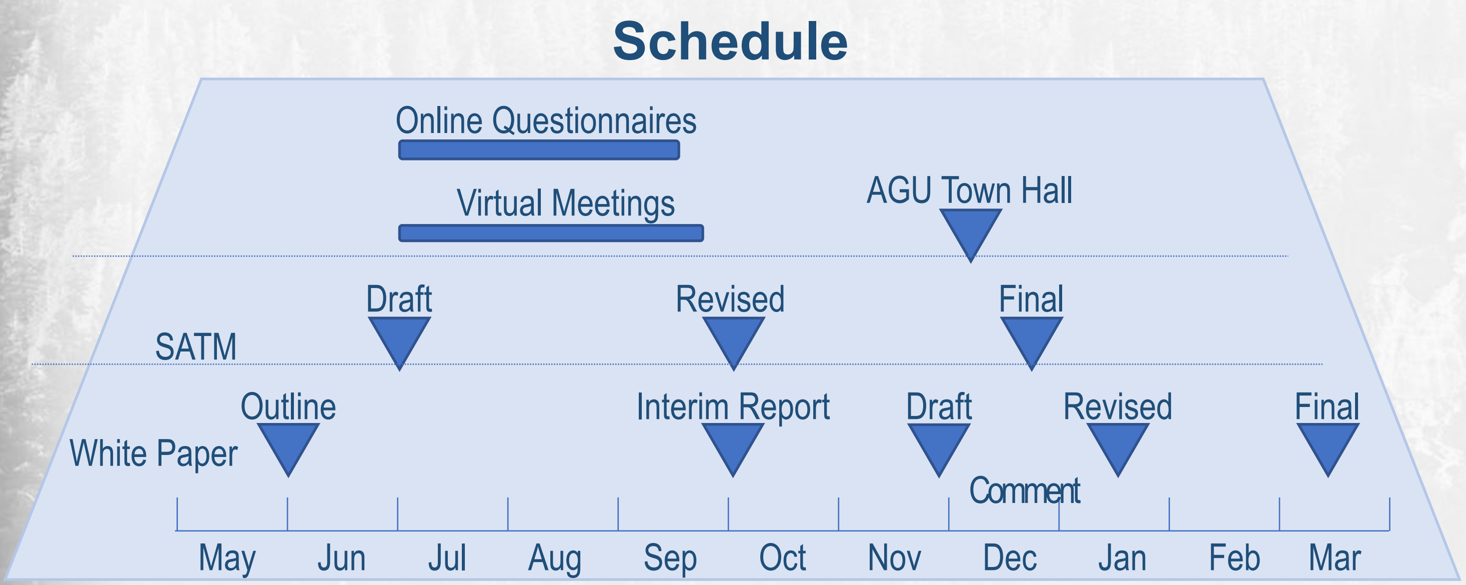
Robert Treuhaft

Vegetation Structure

Konrad Wessel

STV DSI Schedule

This Study



Next Steps

- Incubation studies
- Technology maturation
- Inform next decadal survey (~5 years out)
- Leverage existing data, missions, activities

Contact: stv-leads@list.jpl.nasa.gov

STV Study Update

Community Engagement

Kick-off Plenary, July 9, 2020, 300 attendees

July: Science & Application Breakouts, averaging 51 attendees
- Solid Earth, Vegetation, Cryosphere, Hydrology, Bathymetry

August: Objectives and Product Needs Questionnaire
- 149 responses

September: Technology Breakouts, averaging 49 attendees
- Lidar, Radar, Stereo Photogrammetry, Information Systems

September: Current and Emerging Technology Quad Charts
- 60 responses

White Paper Schedule

October 29: Draft delivered to HASA HQ

Late November: Revision incorporating HQ feedback

December 3: AGU STV Townhall
- Draft summarized
- Release for community comment end of AGU

Dec - Jan: Revision based on comments

End of February: Delivery of final White Paper

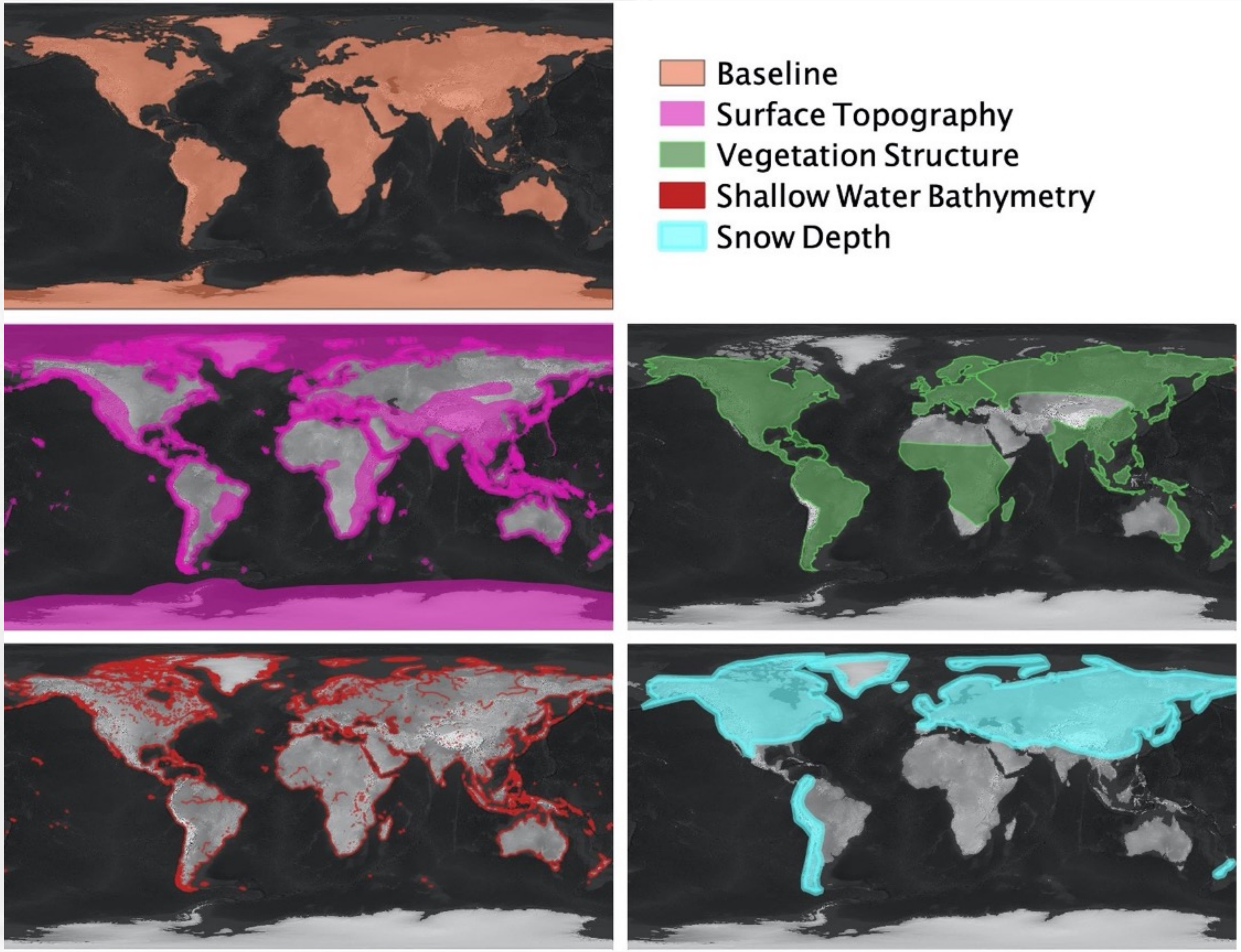
Key Preliminary Findings

Need global baseline mapping and high-resolution for observing change

New Observing Strategy architecture best addresses STV needs
- Multiple platforms and sensors on orbital and suborbital assets

White Paper

STV Preliminary Coverage Maps

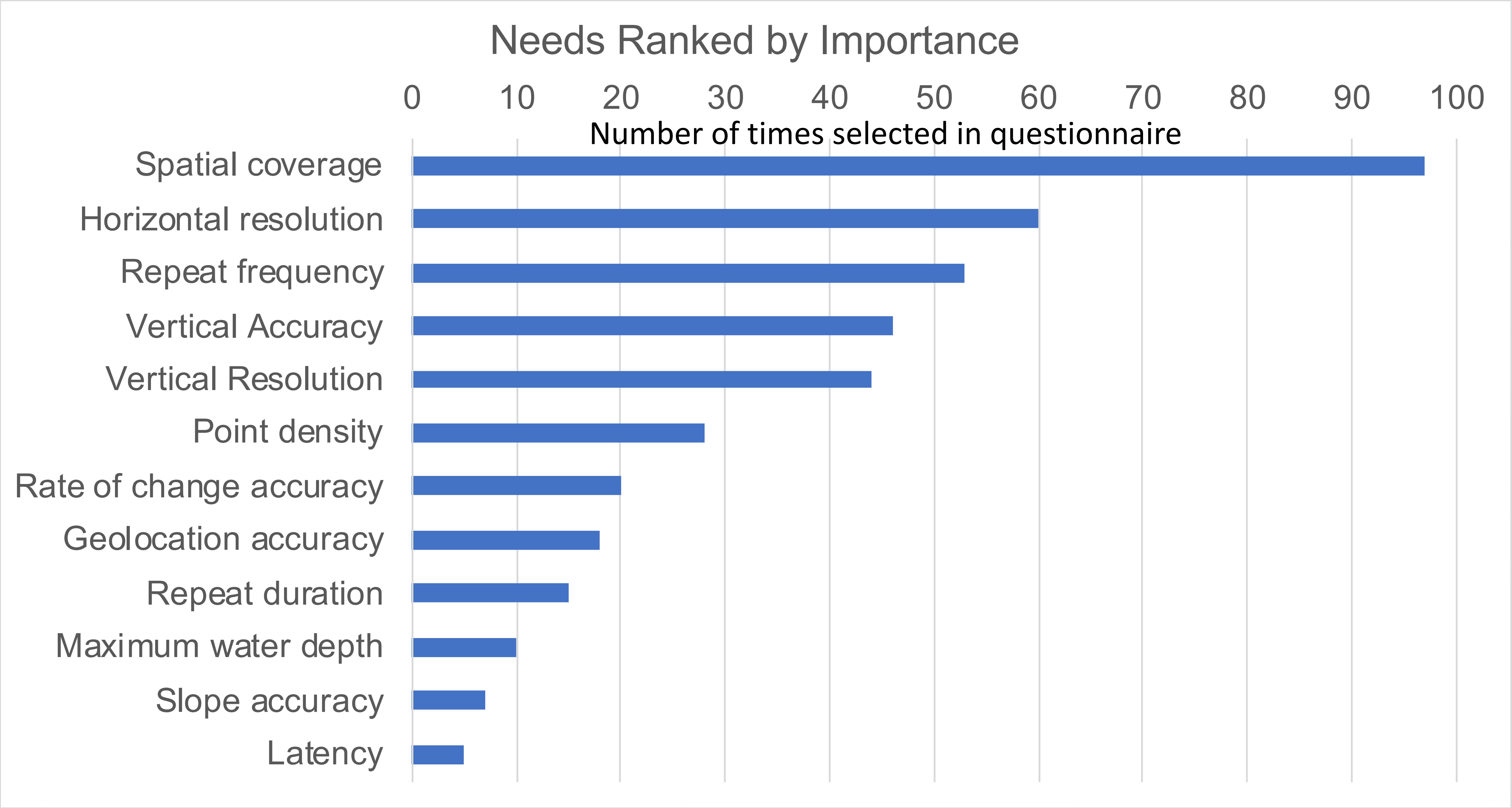


SATM Goals, Objectives and Product Needs

Science or Application				
Goal	Objective	Source	Primary Discipline	Area of Interest

Spatial Needs							
Coverage (%)		Grid or Profile Horizontal Resolution (m)		Point Cloud or Mesh Density (points per sq m)		Vegetation 3D Structure Vertical Resolution (m)	
Bathymetry Maximum Depth (m)		Geolocation Accuracy (m)		Vertical Accuracy (m)		Slope Accuracy (rise over run)	
Aspirational	Threshold	Aspirational	Threshold	Aspirational	Threshold	Aspirational	Threshold

Temporal Needs							
Latency (days)		Repeat Frequency (days)		Repeat Duration (months)		Rate of Change Accuracy (m per year)	
Aspirational	Threshold	Aspirational	Threshold	Aspirational	Threshold	Aspirational	Threshold



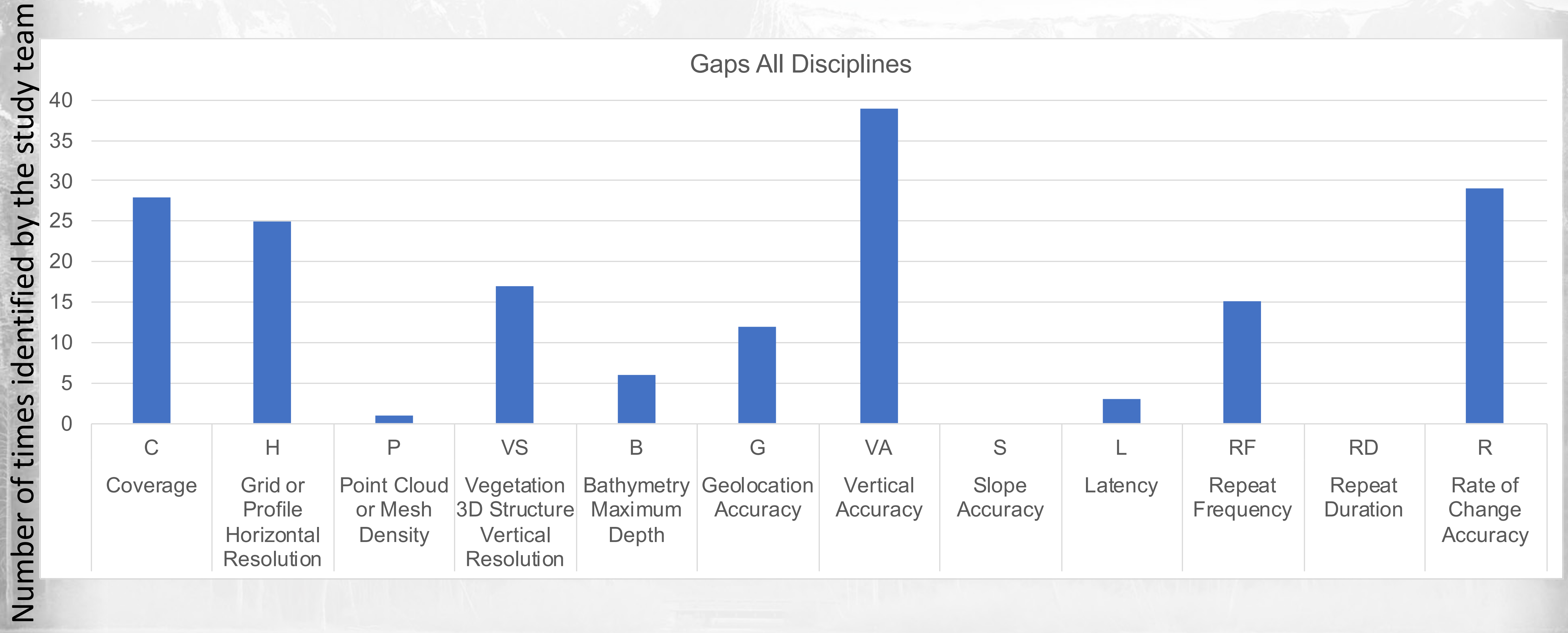
Needs Ranked by Importance
0 10 20 30 40 50 60 70 80 90 100
Number of times selected in questionnaire
Spatial coverage
Horizontal resolution
Repeat frequency
Vertical Accuracy
Vertical Resolution
Point density
Rate of change accuracy
Geolocation accuracy
Repeat duration
Maximum water depth
Slope accuracy
Latency

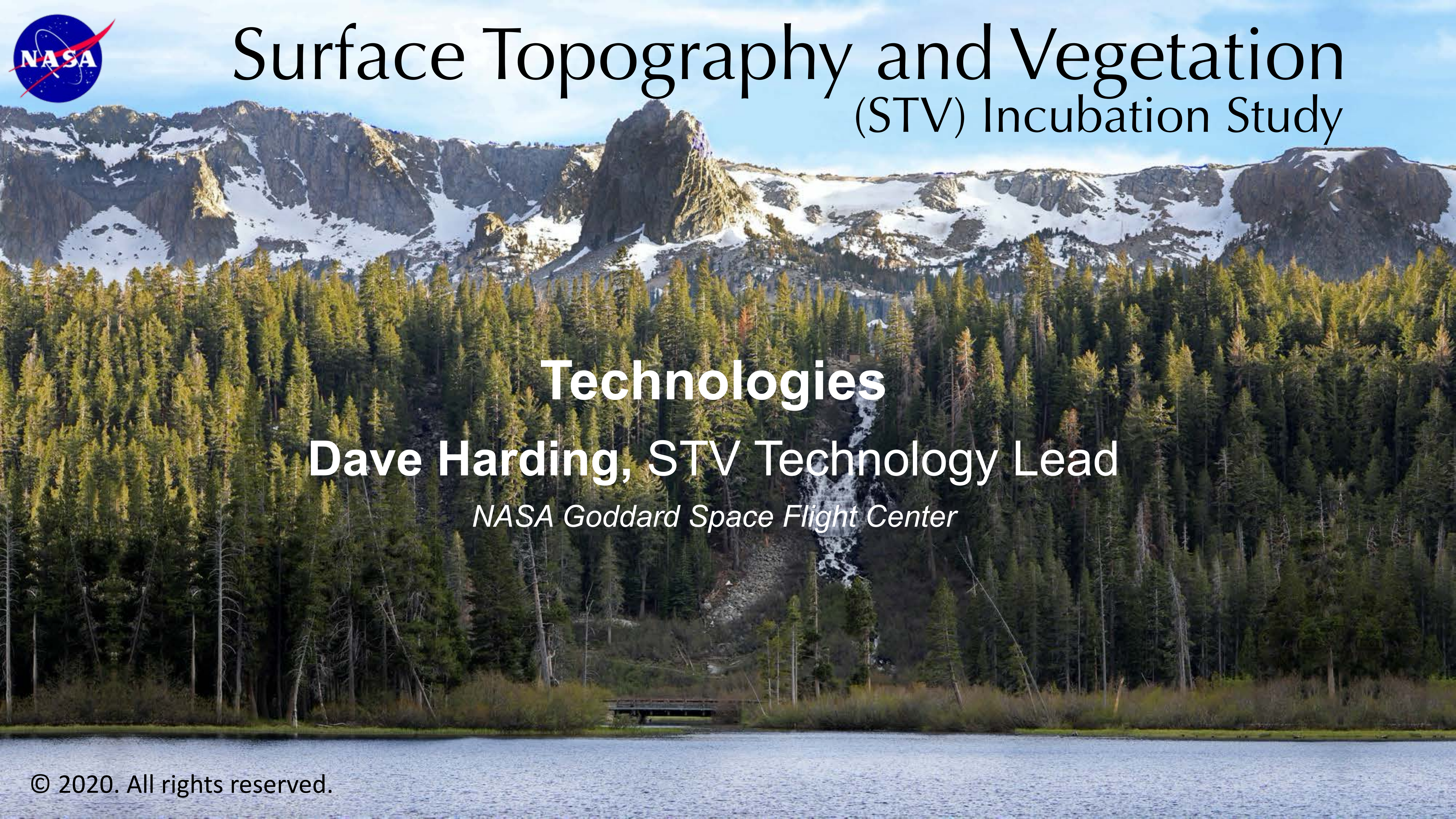
DRAFT Preliminary Measurement Needs Summary

Parameter		Aspirational			Threshold		
		Median (rounded)	Most Stringent Need	Most Stringent Need Discipline	Median (rounded)	Most Stringent Need	Most Stringent Need Discipline
Coverage Area of Interest	%	85	99	Cryosphere	60	70	Cryosphere
Latency	Days	10	1	Hydrology	40	5	Solid Earth
Duration	Years	9	14	Cryosphere	3	8	Cryosphere
Repeat Frequency	Months	0.5	0.03	Solid Earth	3	0.2	Solid Earth
Horizontal Resolution	m	5	1	Solid Earth	25	2	Solid Earth
Vertical Accuracy	m	0.3	0.2	Solid Earth | Appl.	1.0	0.6	Solid Earth | Appl.
Vegetation Vertical Resolution	m	1	0.1	Coastal	2	0.2	Coastal
Bathymetry Max Depth	m	25	100	Solid Earth	10	25	Solid Earth
Geolocation Accuracy	m	2	0.5	Solid Earth	5	2	Solid Earth
Rate of Change Accuracy	cm/yr	10	1.0	Solid Earth	25	5.0	Solid Earth

Under Review/Subject to Change

Gaps Summary for All Disciplines





Surface Topography and Vegetation (STV) Incubation Study

Technologies

Dave Harding, STV Technology Lead

NASA Goddard Space Flight Center

Technology Scope

Instrumentation

- Sensors
- Sensor-specific processing and analysis methods

Information systems

- Hardware or software for assessment or operation of observing systems, sensor webs, or multi-source data fusion and analysis

Platforms

- UAV, aircraft or satellites and systems for on-platform data processing and transmission

Scale

- Regional to global data collection
- Local data collection for a limited number of sites is out of scope

Identifying Technology Gaps and Potential Ways to Fill Them

Current Technology Solutions		Identified Gaps		Potential Activities to Close Gaps					
Instrumentation, Information Systems and Platforms	Which requirements are currently met?	Scientific Knowledge	Technology Capabilities	Simulations	Experiments	Existing Data Analysis	Instrumentation Development	Information Systems Development	Platform Development

Technology breakout sessions:

- **Lidar, September 8, 2020**
- **Stereo Photogrammetry, September 9, 2020**
- **Radar, September 10, 2020**
- **Information Systems, September 15, 2020**

Solicited quad charts on current and emerging technologies

NASA ESTO 2021 solicitation will request proposals for filling gaps

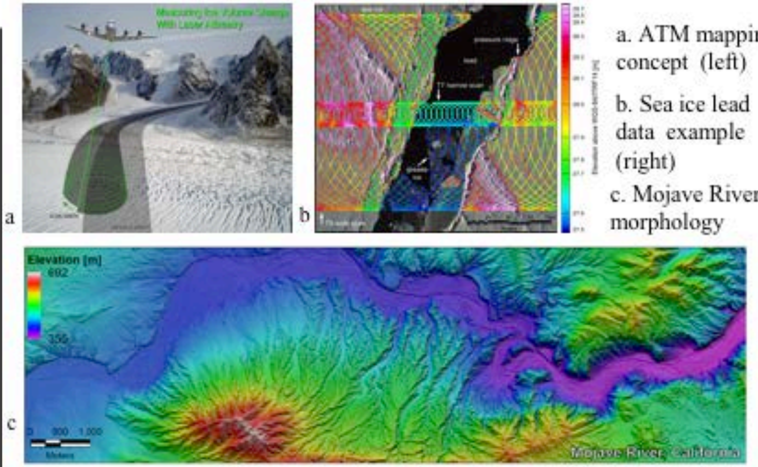
Example Current Technology (TRL 7 - 9, operational)

NASA Airborne Topographic Mapper (ATM)

Dr Michael Studinger NASA GSFC Code 615 (michael.studinger@nasa.gov)

Summary

- The Airborne Topographic Mapper (ATM) is an airborne scanning lidar mapping sensor that measures geodetic-quality topography of features such as: river channel morphology, volcanoes, impact craters, glaciers, and polar land/sea ice.
- Incorporates laser with multi-trigger waveform recording, GNSS, attitude sensor, and aircraft steering subsystems.
- ATM instrument suite includes nadir visible and thermal cameras, and hyperspectral scanner.
- Instrument descriptions and evaluations of measurements published in >500 papers.
- https://atm.wff.nasa.gov/



a. ATM mapping concept (left)
b. Sea ice lead data example (right)
c. Mojave River morphology

Status

- ATM's Current Technical Readiness Level- TRL 9
- ATM has conducted precise topographic mapping for over 26 years.
- ATM has flown on a wide variety of aircraft (P-3, DC-8, C-130, Twin Otter and Gulfstream V) from NASA, NOAA, NCAR, and commercial suppliers.
- ATM was a principal instrument for NASA's Operation IceBridge (2009-2019) and earlier programs for monitoring polar land and sea ice elevation changes, coastal change mapping, ocean wave studies, and geomorphology research.

Co-Is/Partners: NOAA, USGS, CRREL, NRL

Performance

- ATM produces HDF5 format georeferenced point elevations with multi-trigger waveform digitization from ~75 cm diameter laser footprint at 10KHz. Elevation accuracy <5 cm. Single pass coverage dependent on platform attitude and speed on the order of 0.5 to 2 elevations/m2 (overlapping passes increase density).
- ATM can provide quick data processing in 1 hour, high-precision processing in 1 month.
- ATM's extremely long GPS baseline techniques and flexible aircraft capabilities provide global mapping coverage with accuracy of <10 cm even at the poles.

Citations: https://atm.wff.nasa.gov/publications/

Example Emerging Technology (TRL 1- 6, in development)

Distributed Aperture Radar Tomographic Sensors (DARTS)

PI: Marco Lavalle, JPL/Caltech

Objectives

Goal:

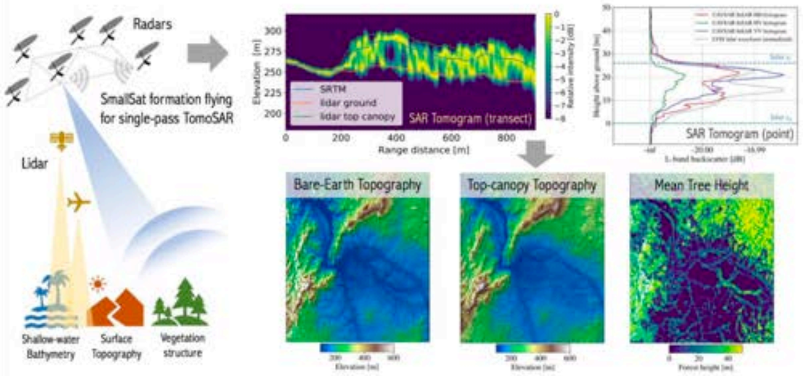
Mature and demonstrate a set of technologies that, when coupled with recent developments in miniaturized spaceborne radars, will enable formations of satellites to perform global vegetation structure and surface topography measurements via simultaneous SAR tomography technique.

Specific objectives:

1. Design, build and test a distributed system to synchronize timing, clock, relative position and sensor data for all of the distributed elements.
2. Miniaturize the distributed phase-coherent radar system
3. Design the instrument architecture and orbital configuration for 3D vegetation structure and surface topography.
4. Test SmallSat compatible L-band deployable antenna

Website: NASA ESTO IIP-19 funded tasks

One or more satellite(s) transmit a radar signal and multiple spacecrafts in close formation receive the scattered echoes, which are coherently processed into *tomograms* (conceptually similar to lidar *waveforms*)



Approach

- Develop and assess synchronization and relative localization algorithms via field/bench tests
- Generate radar tomograms from synchronized signals acquired by small unmanned aircraft systems (sUASs) for changing geometry/site
- Conduct integrated trade-study analysis with orbital, scene, radar, and platform parameters via simulations informed by synchronization/localization algorithm assessment
- Build and test light-weight, deployable, antenna with mechanical support for Transmit/Receive and Receive-only SmallSats

Co-Is/Partners

Team is a synergy between the JPL Radar Section (334) and other JPL Sections (e.g., 335) in collaboration with Caltech (Prof. S. Chung).

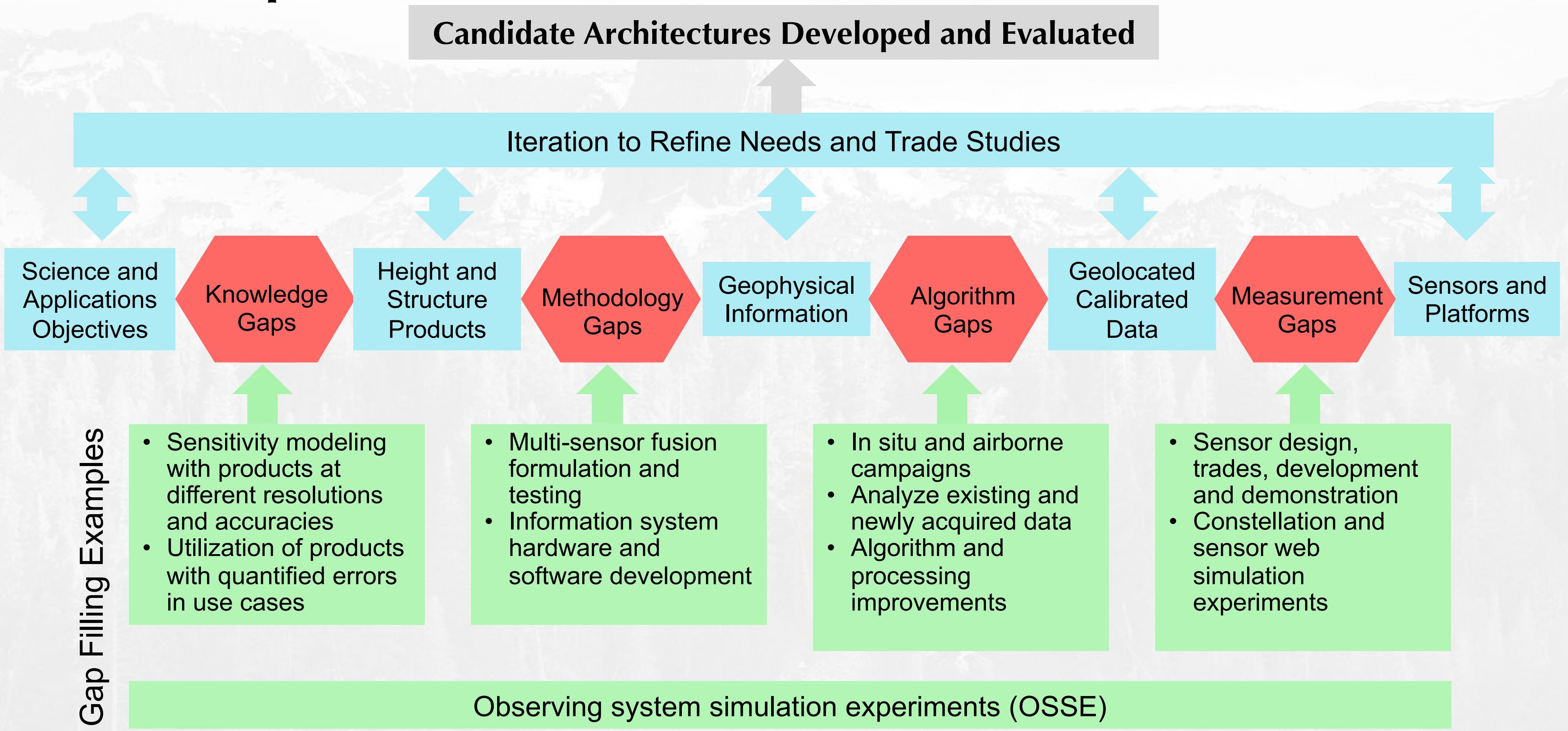
Technical Readiness Level

- Current Technical Readiness Level = 2/3
- With current funded IIP resources, expected TRL = 5
- TRL in 5 years if resources are available = 7

Additional Challenges

- Conversion of radar tomograms into L3 products
- Further radar miniaturization (e.g. leveraging RF photonics)
- Integrated TomoSAR performances leveraging existing missions (SAR or GNSS)
- Data volume, on-board processing and downlink
- Multi-frequency TomoSAR data collection with airborne SAR

STV Gaps Framework



Knowledge gaps:	the understanding of product quality needed to accomplish science and applications objectives is inadequate
Methodology gaps:	the approaches to derive height products from geophysical information are inadequate
Algorithm gaps:	the solutions to derive geophysical information from data are inadequate
Measurement gaps:	the sensor and platform assets to acquire needed data are inadequate

Technology Maturity for STV Observables

		Lidar	Radar	Stereo Photogrammetry	Information Systems
Surface Topography	Orbital	Wide area coverage; resolution; small footprint; cryosphere surface; sustained repeat frequency	Global coverage of DSM and DTM; High resolution DTM/DSM in bare-surface and vegetated areas. Change detection and elevation changes. Challenge meeting cryosphere gaps	Useful for bare surfaces. Vegetated surfaces may require fusion with other sensors	Change detection Cloud avoidance Landscape analysis Multi-sensor data fusion Onboard processing Smart Tasking
	Suborbital	Mature with narrow coverage and high resolution	Mature for local to regional	Wide area coverage; haze poses a problem	
		High altitude, long duration platforms	High altitude, long duration platforms		
Vegetation Structure	Orbital	Wide area coverage; ground detection. Calibration of height and AGB with sampling.	Wide area coverage; Vegetation height/AGB with PolInSAR and TomoSAR. Change detection with repeated phase-height PolInSAR/TomoSAR observations	Vegetation height and outer canopy profile. Internal structure requires fusion	Algorithms for accuracy and error estimation Change detection Cloud avoidance Multi-sensor fusion Onboard processing Smart Tasking
	Suborbital	Mature for local to regional	Validation of spaceborne performance for structure and structure rate of change	CONUS High resolution vegetation height and outer canopy profile.	
		High altitude, long duration platforms			

		Lidar	Radar	Stereo Photogrammetry	Information Systems
Shallow Water Bathymetry	Orbital	Wide area coverage; penetration depth, as a function of water clarity	Limited to mapping shallow channel patterns from radar backscatter or coarse, global ocean bathymetry estimates from radar altimetry sea surface topography measurement	Advancing from multiple on-orbit examples	Advance from local studies combining lidar and optical imagery Algorithms for accuracy and error estimation
	Suborbital	Penetration depth as a function of water clarity		Advancing from local to regional use. Need robust refraction correction procedures/ algorithms integrated into photogrammetric software.	
		High altitude, long duration platforms			
Snow Depth	Orbital	Wide area coverage; snow identification	Wide area coverage; snow accumulation	Advancing from local area examples	Cloud avoidance Multi-sensor fusion Point cloud differencing Smart Tasking
	Suborbital	Repeat frequency	Regional coverage; snow accumulation; potential SWE estimation.	Advancing from local area examples	
		High altitude, long duration platforms			

Mature | Being Advanced | Challenging

Example Gaps and Activities

Lidar gap description	Potential gap filling activities
Limited number of profiles or narrow swath causing insufficient coverage (C, RF)	• Instrument investments to develop and demonstrate improved measurement efficiencies for methods, components, subsystems and systems • Platform investments to improve available power (e.g. larger battery storage capacity for nighttime-operation, solar array efficiency) • Analysis of existing or newly acquired airborne swath mapping data to determine what sampling density and footprint size are required to meet STV requirements, evaluated as a function of land cover and topographic relief • Algorithm and model development using existing or newly acquired concurrent multi-sensor data to develop optimal fusion methods for wide-area height and bathymetry mapping, evaluated as a function of scaled spatial and vertical resolutions and assessing combinations of lidar, InSAR, radar altimetry, stereo and spectroscopic sensors

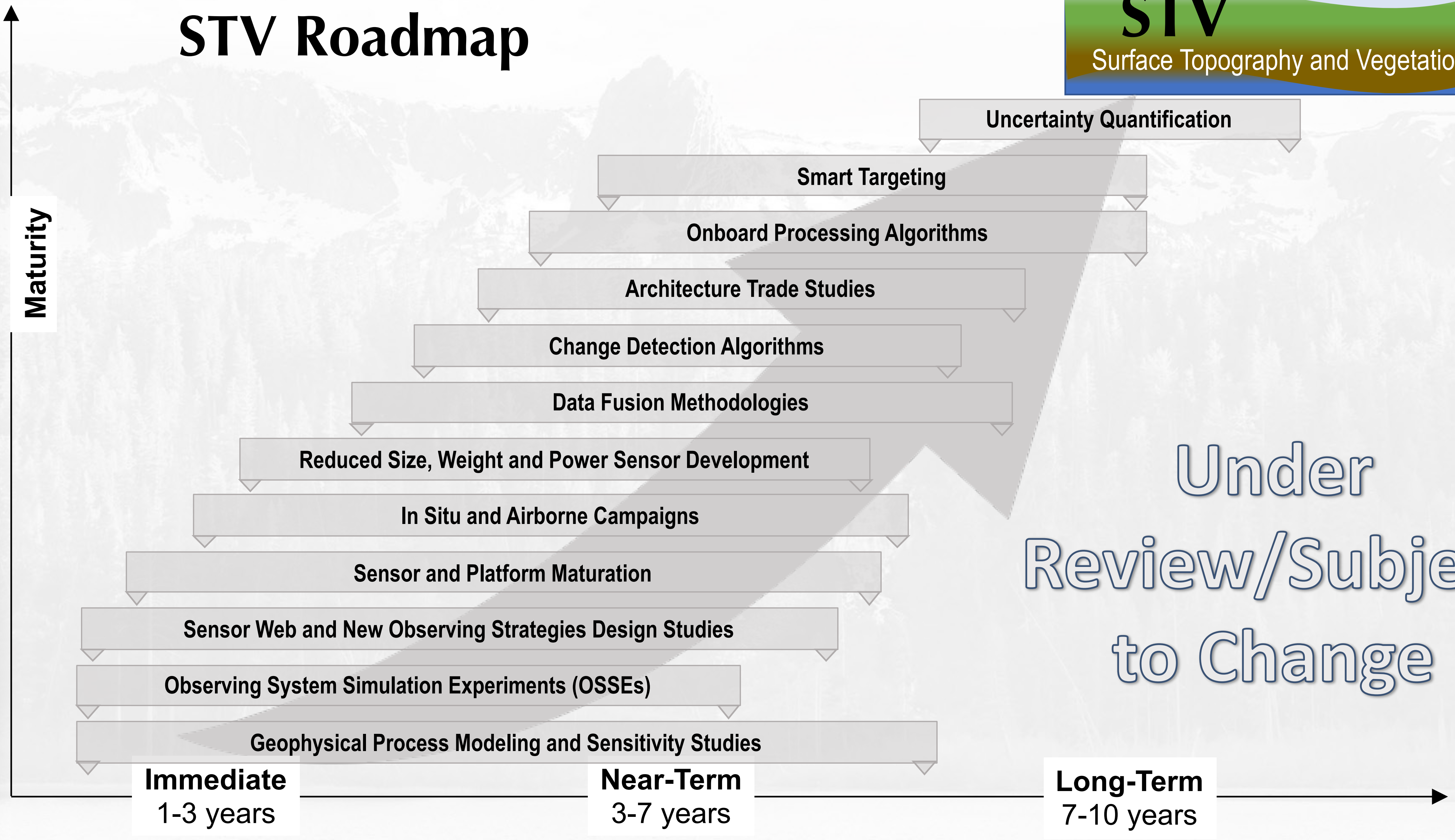
Stereo photogrammetry gap description	Potential gap filling activities
Large data volumes for high-resolution swath mapping can exceed the on-board processing, storage and/or downlink capacity for satellites or long-duration, airborne platforms. (C)	• Explore onboard processing to reduce the amount of downloaded data • Develop new processing algorithms that utilize multiple samples to estimate and reduce error • Develop electronics for high capacity SmallSat missions to efficiently acquire, process, store and transmit massive volumes of data that 3D imaging requires. • Consider lidar-comm for downlink.

Radar Gap description	Potential gap filling activities
Optimal features of the TomoSAR profiles to be used in biophysical descriptor estimation are poorly known. TomoSAR profiles can be thought of as resulting from the function of many baseline amplitudes and phases which best produces the radar power profile. But this function may not be the best one from which to estimate, for example, aboveground biomass (RF, VA, R)	• Conduct field, lidar and TomoSAR/PolInSAR airborne/UAS experiments in single-pass (fixed baseline) and repeat-track modes • Find the lidar and TomoSAR profile features (height, H75, Fourier transform...) which are most sensitive to biophysical features such as AGB, leaf area density, habitat, species richness, abundance, and diversity • Repeat the above experiments 10 times per year for 3 years to develop technology for "change" in each of the above • Multiple forest types, if possible

Information Systems Gap description	Potential gap filling activities
Insufficient capabilities for multi-sensor data fusion methods and algorithms, accounting for differences in - measurement physics (e.g. radar vs. lidar) - imaging geometries (nadir vs. side looking) - horizontal resolution - vertical resolution - acquisition times (sun angle) (C, RF, VA, G, H, VS, R)	• Combined in situ, airborne and satellite data collection campaigns, designed for height mapping purposes, to acquire multi-sensor data sets for analysis and algorithm and model development. • Algorithm and model development using existing or newly acquired concurrent multi-sensor data to develop optimal fusion methods for identification of features, evaluated as a function of scaled spatial and vertical resolutions and assessing combinations of lidar, high-resolution images (panchromatic, multispectral and/or hyperspectral) and multi-frequency polarimetric SAR sensors

STV Roadmap

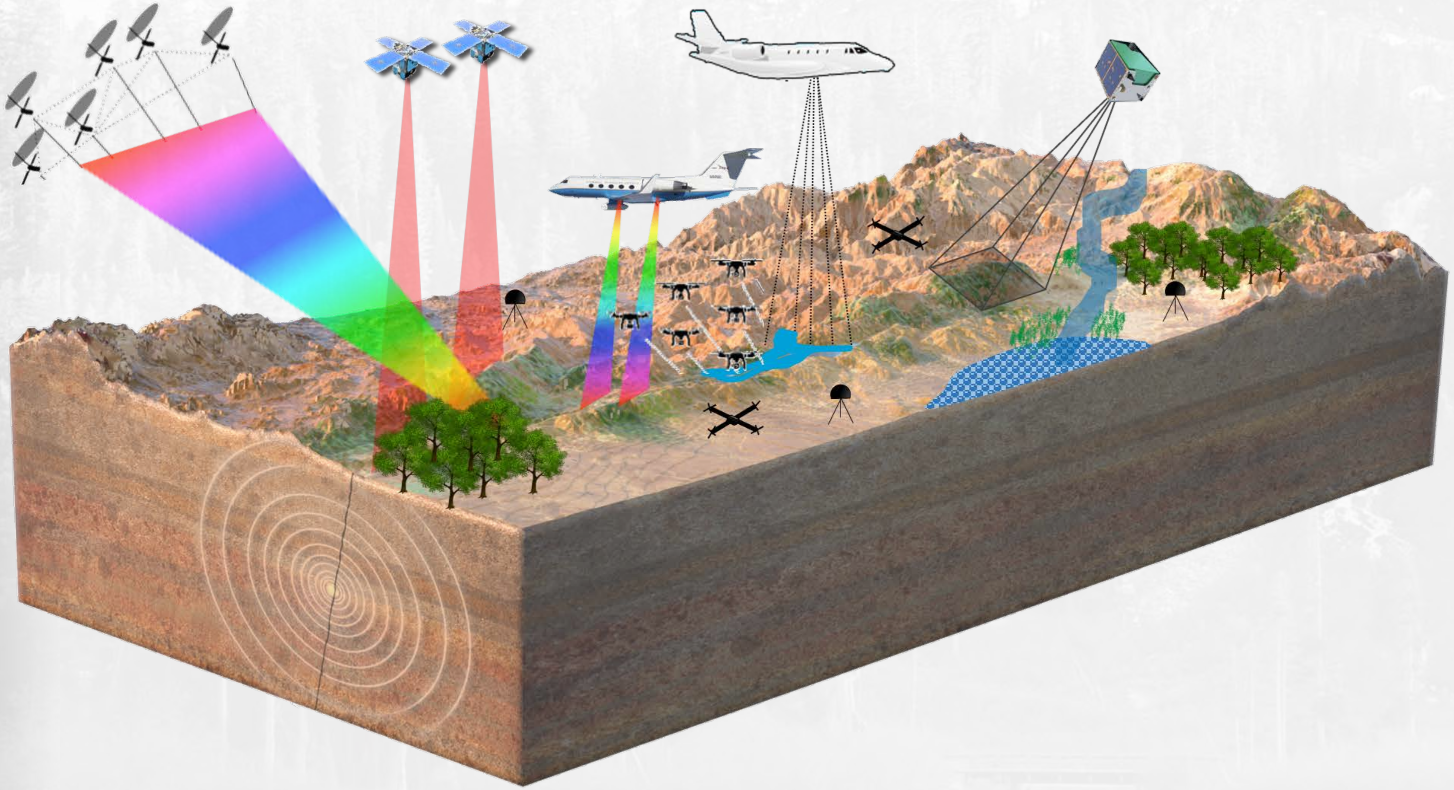
STV
Surface Topography and Vegetation



Under Review/Subject to Change

Key Preliminary Technology Finding

- **Architecture of multiple platforms and sensors on orbital and suborbital assets would best address STV needs**



New Observing Strategies Paradigm

- **Multiple collaborative sensor nodes producing measurements integrated from multiple vantage points and in multiple dimensions (spatial, spectral, temporal, radiometric)**
- **Provide a dynamic and more complete picture of physical processes or natural phenomena**

Discussion