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.

<table>
<thead>
<tr>
<th>Program</th>
<th>Description</th>
<th>Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument Incubator Program (IIP)</td>
<td>Earth remote sensing instrument development from concept through breadboard and demonstration</td>
<td>19 projects awarded in Oct 2019. Solicitations planned in FY21 and FY23. Average award: $4.5M (3 years). Average selection rate: 23.2%</td>
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<tr>
<td>Advanced Information Systems Technology (AIST)</td>
<td>Innovative on-orbit and ground capabilities for communication, processing, and management of remotely sensed data and the efficient generation of data products</td>
<td>22 projects awarded in Sept 2019. Solicitations planned in FY21 and FY23. Average award: $1.2M (2 years). Average selection rate: 19.6%</td>
</tr>
<tr>
<td>Decadal Survey Incubation (DSI)</td>
<td>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</td>
<td>2 Study teams awarded in FY20. Solicitation planned in FY21</td>
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</tbody>
</table>

STV 2020 AGU Town Hall 12/3/2020
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):

<table>
<thead>
<tr>
<th></th>
<th>FY20</th>
<th>FY21</th>
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<td>20.0</td>
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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

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<tr>
<th>Agency</th>
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<td>DSI</td>
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<td>Q1</td>
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</table>
### TABLE S.2 Continued

<table>
<thead>
<tr>
<th>Targeted Observable</th>
<th>Science/Applications Summary</th>
<th>Candidate Measurement Approach</th>
<th>Designated</th>
<th>Explorer</th>
<th>Incubation</th>
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</thead>
<tbody>
<tr>
<td>Planetary Boundary Layer</td>
<td><strong>Diurnal 3D PBL thermodynamic properties and 2D PBL structure</strong> to understand the impact of PBL processes on weather and air quality through high vertical and temporal profiling of PBL temperature, moisture, and heights</td>
<td>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</td>
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<tr>
<td>Surface Topography and Vegetation</td>
<td><strong>High-resolution global topography</strong>, including bare surface land topography, ice topography, vegetation structure, and shallow water bathymetry</td>
<td>Radar; or lidar*</td>
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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](mailto:robert.bauer@nasa.gov)

<table>
<thead>
<tr>
<th>Topic</th>
<th>Program Scientist</th>
<th>Technology Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Topography &amp; Vegetation (STV)</td>
<td>Ben Phillips <a href="mailto:ben.phillips@nasa.gov">ben.phillips@nasa.gov</a></td>
<td>Bob Connerton <a href="mailto:robert.m.connerton@nasa.gov">robert.m.connerton@nasa.gov</a></td>
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</tbody>
</table>

*Along with:*
- Hank Margolis [hank.a.margolis@nasa.gov](mailto:hank.a.margolis@nasa.gov)
- Thorsten Markus [thorsten.markus@nasa.gov](mailto: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

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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]

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
STV DSI Schedule

This Study

Schedule

Online Questionnaires
Virtual Meetings
AGU Town Hall

SATM
Draft
Revised
Final

Outline
Interim Report
Draft
Revised
Final

May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar

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

i. Executive Summary
1. Background
2. STV Targeted Observables
4. Current and Emerging Sensors, Platforms, and Information Systems
5. Gaps and Gap-filling Activities
6. Key Findings and Preliminary Roadmap

Appendix A: Preliminary SATM
Appendix B: Team Member Contributions
Appendix C: Community Engagement
Appendix D: Product Needs Questionnaire
Appendix E: Technology Quad Charts
   Acronyms
   References
STV Preliminary Coverage Maps
# SATM Goals, Objectives and Product Needs

## Science or Application

<table>
<thead>
<tr>
<th>Goal</th>
<th>Objective</th>
<th>Source</th>
<th>Primary Discipline</th>
<th>Area of Interest</th>
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## Spatial Needs

<table>
<thead>
<tr>
<th>Coverage (%)</th>
<th>Grid or Profile Horizontal Resolution (m)</th>
<th>Point Cloud or Mesh Density (points per sq m)</th>
<th>Vegetation 3D Structure Vertical Resolution (m)</th>
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<tr>
<th>Bathymetry Maximum Depth (m)</th>
<th>Geolocation Accuracy (m)</th>
<th>Vertical Accuracy (m)</th>
<th>Slope Accuracy (rise over run)</th>
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## Temporal Needs

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<tr>
<th>Latency (days)</th>
<th>Repeat Frequency (days)</th>
<th>Repeat Duration (months)</th>
<th>Rate of Change Accuracy (m per year)</th>
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<tbody>
<tr>
<td>Aspirational</td>
<td>Threshold</td>
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</table>
Needs Ranked by Importance

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

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<td>Median (rounded)</td>
<td>Most Stringent Need Discipline</td>
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<td>Coverage Area of Interest</td>
<td>%</td>
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<td>Duration</td>
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<td>Vertical Accuracy</td>
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<td>Vegetation Vertical Resolution</td>
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<tr>
<td>Bathymetry Max Depth</td>
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<td>Geolocation Accuracy</td>
<td>m</td>
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<td>Rate of Change Accuracy</td>
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Gaps Summary for All Disciplines

Number of times identified by the study team

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<th>Coverage</th>
<th>Grid or Profile Horizontal Resolution</th>
<th>Point Cloud or Mesh Density</th>
<th>Vegetation Structure 3D Vertical Resolution</th>
<th>Bathymetry Maximum Depth</th>
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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

<table>
<thead>
<tr>
<th>Current Technology Solutions</th>
<th>Identified Gaps</th>
<th>Potential Activities to Close Gaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrumentation, Information Systems and Platforms</td>
<td>Which requirements are currently met?</td>
<td>Scientific Knowledge</td>
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</tbody>
</table>

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/](https://atm.wff.nasa.gov/)

**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/](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

**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/visibility
- 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

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 waveform)
**STV Gaps Framework**

### Observer system simulation experiments (OSSE)

<table>
<thead>
<tr>
<th>Gap Filling Examples</th>
<th>Knowledge gaps:</th>
<th>Methodology gaps:</th>
<th>Algorithm gaps:</th>
<th>Measurement gaps:</th>
</tr>
</thead>
</table>

- **Knowledge gaps:**
  - Sensitivity modeling with products at different resolutions and accuracies
  - Utilization of products with quantified errors in use cases

- **Methodology gaps:**
  - Multi-sensor fusion formulation and testing
  - Information system hardware and software development

- **Algorithm gaps:**
  - In situ and airborne campaigns
  - Analyze existing and newly acquired data
  - Algorithm and processing improvements

- **Measurement gaps:**
  - Sensor design, trades, development and demonstration
  - Constellation and sensor web simulation experiments

---

**Candidate Architectures Developed and Evaluated**

**Iteration to Refine Needs and Trade Studies**
# Technology Maturity for STV Observables

<table>
<thead>
<tr>
<th>Surface Topography</th>
<th>Lidar</th>
<th>Radar</th>
<th>Stereo Photogrammetry</th>
<th>Information Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbital</td>
<td>Wide area coverage; resolution; small footprint; cryosphere surface; sustained repeat frequency</td>
<td>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</td>
<td>Useful for bare surfaces. Vegetated surfaces may require fusion with other sensors</td>
<td>Change detection</td>
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<tr>
<td>Suborbital</td>
<td>Mixture with narrow coverage and high resolution</td>
<td>Mixture for local to regional</td>
<td>Wide area coverage; haze poses a problem</td>
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<tr>
<td></td>
<td>High altitude, long duration platforms</td>
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<tr>
<td>Vegetation Structure</td>
<td>LIDAR</td>
<td>RADAR</td>
<td>STEREO PHOTOGRAMMETRY</td>
<td>INFORMATION SYSTEMS</td>
</tr>
<tr>
<td>Orbital</td>
<td>Wide area coverage; ground detection</td>
<td>Wide area coverage; Vegetation height/AGB with PolInSAR and TomoSAR. Change detection with repeated phase-height PolInSAR/TomoSAR observations</td>
<td>Vegetation height and outer canopy profile. Internal structure requires fusion</td>
<td>Algorithms for accuracy and error estimation</td>
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<tr>
<td>Suborbital</td>
<td>Mixture for local to regional</td>
<td>Validation of airborne performances for structure and structure rate of change</td>
<td>CONUS High resolution vegetation height and outer canopy profile.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High altitude, long duration platforms</td>
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</tbody>
</table>

| Shallow Water Bathymetry | LIDAR | RADAR | STEREO PHOTOGRAMMETRY | INFORMATION SYSTEMS |
| 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 |
| Suborbital | Penetration depth as a function of water clarity | High altitude, long duration platforms | Onboard processing | Smart Tasking | Algorithms for accuracy and error estimation |

| Snow Depth | LIDAR | RADAR | STEREO PHOTOGRAMMETRY | INFORMATION SYSTEMS |
| Orbital | Wide area coverage; snow accumulation | 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. | | | | | | |

**Maturity Levels:**
- Mature
- Being Advanced
- Challenging
## Example Gaps and Activities

<table>
<thead>
<tr>
<th>Lidar gap description</th>
<th>Potential gap filling activities</th>
</tr>
</thead>
</table>
| 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 |

<table>
<thead>
<tr>
<th>Radar Gap description</th>
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</table>
| 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/PollInSAR 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 |

<table>
<thead>
<tr>
<th>Stereo photogrammetry gap description</th>
<th>Potential gap filling activities</th>
</tr>
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</table>
| 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. |

<table>
<thead>
<tr>
<th>Information Systems Gap description</th>
<th>Potential gap filling activities</th>
</tr>
</thead>
</table>
| 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

Uncertainty Quantification

- Smart Targeting
- Onboard Processing Algorithms
- Architecture Trade Studies
- Change Detection Algorithms
- Data Fusion Methodologies
- Reduced Size, Weight and Power Sensor Development
- In Situ and Airborne Campaigns
- Sensor and Platform Maturation
- Sensor Web and New Observing Strategies Design Studies
- Observing System Simulation Experiments (OSSEs)
- Geophysical Process Modeling and Sensitivity Studies

Immediate
1-3 years

Near-Term
3-7 years

Long-Term
7-10 years
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