Surface Topography and Vegetation (STV)
Airborne Surface, Cryosphere, Ecosystem, and Nearshore Topography (ASCENT) Campaigns
Planning Document

22 August 2024

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Background

Following the 2017 Earth Science and Applications from Space Decadal Survey, NASA has selected Surface Topography and Vegetation (STV) teams to mature STV science and technology for a future observing system. The current team was selected through the ROSES-2021 Decadal Survey Incubation Program: Science and Technology solicitation. The next team will be selected through the ROSES-2024 program bearing the same name. The Decadal Survey recommended STV to include high-resolution global topography, including bare surface land topography, ice topography, vegetation structure, and shallow water bathymetry. Measurement approaches being studied by the team are lidar, radar, and stereoimaging. A key challenge for STV is separating vegetation structure and bare Earth topography. Further details on STV can be found at https://science.nasa.gov/earth-science/decadal-surveys/decadal-stv/.

This document describes future airborne campaigns that would support maturation of STV. One of the reasons that STV was named as a targeted observable for incubation is that technology maturation is required to reduce implementation risk. The airborne campaigns are designed to improve our knowledge and quantify the limitations of the various measurement approaches for different types of land surface features. These campaigns are also designed to enable intercomparison between measurement types as well as to provide coincident observations suitable for improving data fusion techniques between active and passive systems.

This document provides a framework for future planning and implementation. The initial concept was discussed at the 2023 STV Community Meeting. The findings were compiled and distributed to the STV community via its listerv comprised of over 700 members. The plan was then refined the by STV team at the 2024 June team meeting. We anticipate that the targets and airborne campaigns will be finalized by team members at the time of the campaigns. The recommended STV maturation campaigns are referred to as ASCENT for Airborne Surface, Cryosphere, Ecosystem, and Nearshore Topography.

Need for Airborne STV Measurements

The goal of ASCENT is to provide surrogate data, sampled from a variety of targets and configurations, to develop algorithms to:

1. Separate vegetation from bare Earth topography
2. Separate shallow water from bare Earth topography
3. Fuse data

Lidar, radar, and Stereoimaging methods have differing strengths for contributing to STV (Table 1). Lidar measurements are excellent at determining a digital surface model (DSM) and finding ground returns but can be sparse. Stereoimaging measurements cover a broad area and produce an excellent DSM, though canopy height can be underestimated as tree crowns narrow below the image pixel size. Lidar and stereoimaging observe the surface if not obstructed by clouds. Radar measurements provide broad area coverage while penetrating clouds. Single-frequency radar can penetrate vegetation and, when combined with multi-baseline radar, can provide tomograms of vegetation density profiles. Multi-frequency radar may improve tomograms of vegetation density distribution.

	Radar	**Lidar**	**Stereoimaging**
Observation	Microwave intensity and phase	Light intensity and time of return	Color imagery from different perspectives
Vertical measurement	Height and Vertical Canopy profile	Height and Vertical Canopy profile	Digital Surface Model (DSM) height from range imagery and features from texture
Weather	All Weather	Clear sky	Clear sky
Geo Coverage	Wide Field of View	Canopy profiles, narrow field of view	Wide Field of View

Table 1. Observation types and contribution to STV observable

Measurement Requirements

Data and results from the ASCENT campaigns will inform measurement needs for a future STV observing system. Here we define the ASCENt airborne campaign requirements. A key requirement for ASCENT is that the different measurement types be collected in close time and space proximity (Table 2). This is to facilitate data fusion, particularly for fast moving features, such as leaves blowing or material flowing. Some experiments in the flight configurations might relax this requirement to determine the maximum time separation between measurement types. This is key, as orbit requirements for each technology may vary in the eventual STV observing system.

Category	**Requirement**
Contemporaneous radar, lidar, stereoimaging	Airborne Baseline: Ideally within 1 hour; threshold ≤3 days Similar airspeeds (900 km/hr for jet)
Measurement	Optical / Radar: ≤3m 3D Lidar: < 0.1 m 3D
Coverage	Multiple STV discipline targets Nominal altitude 10–12.5 km (TBD by team) Overlaid swaths (UAVSAR 16 km, LVIS 2 km, QUAKES 12 km)
Availability of Ground Truth Measurements	Contemporaneous UAV and ground measurements
Coordinated with relevant satellites	≤3 days of relevant satellite pass Consideration of ICESat-2, GEDI, optical orbits and timing

Table 2. Key requirements for ASCENT STV maturation airborne campaigns.

Instruments/Payload

The instruments to be flown as part of ASCENT should be a radar, lidar, and stereoimager. The ASCENT project will require aircraft that can accommodate multiple nadir pointing instruments to collect both imagery and lidar. At present we envision that instruments would be flown on two NASA Gulfstream aircraft, although different airborne platforms could be substituted. One would host an airborne radar. The likely radar candidate is AirSAR-NG (Next Gen UAVSAR). UAVSAR will continue to fly on the G-III until the AirSAR-NG debuts on the G-IV in 2026. The instrument operates at L-band, P-band, and Ka-band. SAR-Fusion, which is a visible and short wavelength infrared (VSWIR) side-looking instrument in the direction of the UAVSAR swath can be flown in conjunction. A second aircraft with two nadir ports would host lidar and stereoimaging instruments. A like aircraft would match airspeed in order to collect contemporaneous data. LVIS, G-LiHT, JPL's RIEGL or a similar well-characterized lidar will be used for reference measurements, combined with candidate lidar instrument CASALS. QUAKES-I would provide STV stereoimagery data.

Data collections will largely consist of systematic coverage over large areas to provide contiguous datasets that can then be used for intercomparison. Datasets from different platforms should be acquired contemporaneously. Additional measurements from other aircraft may provide higher resolution data. Final selection of aircraft platforms will be determined by the STV members at time of planning in conjuction with NASA headquarters.

The STV team members will plan acquisitions to coincide with relavent space-based observations (e.g. ICESat-2, NISAR). This includes high-resolution stereoimagery, high-resolution bistatic radar, and laser altimetry. STV team members will lead the tasking request and data acquisition.

ASCENT Campaigns

The current STV team recommends three annual campaigns over representative STV targets (Figure 1, Table 3). Year 1 (tentatively 2025) would cover the east coast, Year 2 the west coast, and Year 3 the Hawaiian Islands in the Pacific. Time of year for the campaigns will be determined by the STV team at time of planning. The campaigns should avoid rainy seasons. Summer is ideal for leaf on campaigns. Winter would be better for leaf off and snow. The challenges to be addressed through ASCENT should be fleshed out by the STV team and in particular the STV science and technology groups in coordinate with an airborne planning group.

Forests. The campaigns should cover temperate, boreal, and tropical forests. The ability to resolve the ground in summer is a challenge for temperate forests and likely establishes a need for leaf off observations. For boreal forests, is it possible to resolve the ground based on vegetation density measurements? How well are tree heights resolved when the crown narrows below the measurement resolution? The team should assess the need for calibration measurements for this and similar cases and identify where there are existing data to complement the ASCENT campaigns.

Bare Earth. Measurements should be collected over steep and shallow slopes to establish the accuracy of each technology in rough terrain. Separating vegetation and bare-earth is a primary challenge of the STV mission. The ability of a remote sensing technology to see through the canopy to measure ground topography is key. This ability may be strongly impacted in terrain with topography. Retrieval of snow and ice depth are also challenging in those environments. Resolving the bottom in shallow water is affected by turbidity—assuming Lidar is the only viable method— and so shallow water environments exhibiting a range of turbidity should be explored.

Study Team Tasks:

- Identify existing field data collection sites.
- Ensure regions are easy to access and friendly to US overflight requests.
- Identify spacecraft overflight tracks of different techniques.
- Develop flight plans that fit within flight allocations that include priority targets.

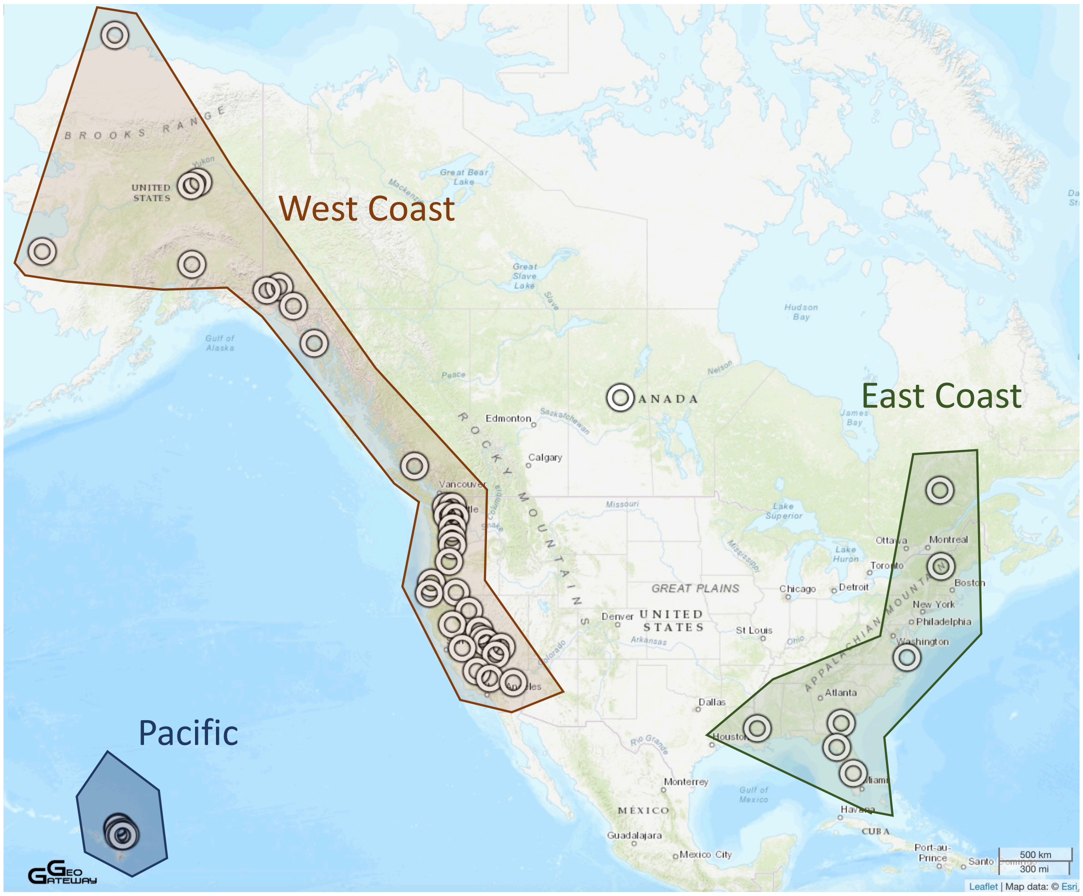

Figure 1. General ASCENT campaign areas and targets.

	West Coast	Pacific	East Coast
Forest			
Temperate Forest	x		x
Tropical		x	
Boreal Forest	x		x
Wetland	x	x	x
Mangrove			x
Leaf on, Leaf off (seasonal changes)	x		x
Solid Earth			
Volanoes	x	x	
Landslides	x		x
Tectonics	x	x	
Steep slopes/gradients	x	x	x
Surface roughness	x	x	x
Hydrology & Coastal			
Emerging Vegetation (wetlands)	x	x	x
Lakes	x		x
River	x		x
Turbidity	x	x	x
Ocean	x	x	x
Rugosity/Roughness	x	x	x
Bottom types	x	x	x
Snow on, Snow off	x		x
Cryosphere			
Permafrost	x		
Glaciers	x		
Sea ice	x		x

Table 3. ASCENT target site characteristics by campaign.

Ground and Near-Surface Validation

In-situ measurements are needed to calibrate and validate the airborne measurements. Therefore, ground truth data must also be collected contemporaneously with the airborne measurements. These data should be collected in representative areas of the overall campaigns. Measurements from small UAS or ground instrumentation can provide ground elevation, vegetation height, and distribution of structure over representative areas to examine efficient methods to calibrate and validate STV observations over broader areas.

These data will allow the team to quantify the performance of the airborne data separately and fused as well as project performance to an observing system.

Data Processing

Lower-level data products from the ASCENT campaigns should be produced by the respective instrument teams and made available to the broader STV team (Table 3). ASCENT instrument teams and STV team members will work on Level 2 and 3 products. STV team members will fuse the data into higher Level 4 STV observables.

Level	Description	Responsibility
L0	Instrument data at full resolution with artifacts removed	Instrument teams
L1	Geo-referenced and time-referenced data at full resolution	Instrument teams
L2	Derived STV variables at full resolution Digital surface model (stereoimaging, lidar) Surface return elevations (lidar) Vegetation density profiles (radar) Point cloud (stereoimaging, lidar)	Instrument teams STV team members
L3	Derived STV variables space-time gridded Digital Terrain Model Canopy height model Vegetation density distribution Water depth Snow depth	Instrument teams STV team members
L4	Fused product of bare Earth and vegetation structure Bare Earth topography (digital terrain model) Canopy height model Vegetation structure (vegetation density distribution) Snow and water depth	STV Team members

Table 4. Preliminary ASCENT data products to be refined by the STV team.

Intercomparison

In situ field measurements are critical to understand differences between measurements collected from stereoimaging, lidar, and radar. The measured surface elevation is likely to be different between each technique and might have coverage gaps. The airborne and field data will provide a well-known validated dataset for assessing and calibrating the measurement techniques needed to generate product from fusion of these measurements. These factors drive the need for observations that are near-contermporeneous, and targeted experiments will help establish the acceptable time difference between observation types. They will also help establish the level of *in situ* measurements that are required to be representative of broader regions to produce accurate data products. Finally, the well understood and characterized data from each technology will be available to evaluate algorithms and improve elevation estimates. The ASCENT data will allow STV team members to develop algorithms that optimize the various datasets individually as well as together.

Summary

The goal of ASCENT is to collect near-contemporaneous lidar, radar, and stereoimaging data. The campaigns will provide surrogate data for space-based performance modeling and science. The current assessment is that ASCENT data should collected with consistent airspeeds, but the STV team at time of planning should conduct a thorough analysis to determine the acceptable time difference between observation types. Flights should oversample targets and lines should be flown to simulate orbit track data. ASCENT will focus on different types of targets representative of STV observing system targets. This includes temperate (leaf on and off) forests, boreal forests, wetlands, bare and vegetated surfaces, steep and shallow surfaces, snow, ice, and permafrost. STV team should create an airborne campaign planning and logistics group. *In situ* ground and near-surface calibration and validation data must be collected for select sites during the campaigns. Equal resources for flight time and data processing to Level 2 products are expected.

Authorship

Writing of this document was led by STV Lead Andrea Donnellan and Technology Co-Lead Craig Glennie. Details of the campaigns were developed at the STV Community and Team Meetings in November 2023 and the STV Team Meeting in June 2024. STV leads contributed to this document.