SnowEx Year-1 Science Traceability Matrix

SnowEx Overarching Question: How much water is stored in Earth's terrestrial snow-covered regions?	
SnowEx Year 1 Fundamental Questions	**Q1 –** What is the distribution of snow-water equivalent (SWE), and the snow energy balance, in different canopy types and densities, and terrain?
	Q2 – What is the sensitivity and accuracy of different SWE sensing techniques in different canopy types, canopy density, and terrain?

Mission Objective and Associated Ancillary Questions	Measurement Requirements	Instrument Functional Requirements	Investigation Functional Requirements	Data Deliverables
1) Quantify SWE in open and forested areas for different canopy densities and terrain (Response to Q1,2) A. What is the spatial variability of SWE in open and forested areas? B. What factors control snow variability in open and forested areas in different terrain? C. What is the sensitivity & accuracy of different sensors to SWE at different scales and under different canopy densities? **2) Quantify snow albedo in open and forested areas for different canopy densities & snow conditions (Response to Q1,2)** A. What is the spatial variability of snow albedo in open and forested areas? B. How does the average albedo of an area scale as we move from point to plot to hectare to stand and domain? C. What is the sensitivity & accuracy of different sensors to snow albedo at different scales?	Site with a range of forest densities & snow conditions, reliable & dry snow, and a wide range of SWE values. Selected sites: - Grand Mesa, Colorado is the primary site. - Nearby Senator Beck basin added as secondary site to investigate Q1 & Q2 in complex terrain. Multi-sensor airborne measurements at a spatial scale <200 m to measure: *Snow water equivalent* - Microwave emission - Radar backscatter time series - Interferometric phase change *Snow depth* - Waveform LiDAR *Spectral BRDF, Albedo* Hyperspectral VIS/SWIR reflected radiance *Snow areal extent* - VIS/NIR imagery (multi- or hyperspectral) - High-res digital photography Concurrent *in situ* ground truth measurements of micro- and macro-snow & forest properties - Depth, density, SWE - Grain size & morphology, - Snow surface roughness - Snow stratigraphy - Snow temperature profile - Forest litter content in the snow surface layer	<u>LiDAR</u> Full-waveform LiDAR system with <1.0 m horizontal resolution and <0.10 m vertical accuracy. <u>Active microwave</u> Dual-pol radar (10 &17 GHz) with spatial resolution of <10 m and a swath width of >100 m, Backscatter sigma 0 to -20 dB <u>Passive microwave</u> Dual-polarized microwave radiometer (minimum bands: 10, 18, & 37 GHz); spatial resolution <200 m, T_B accuracy of ±2K <u>Vis/IR</u> Multi-spectral/multi-angular high resolution radiometer (iFOV: <5°, spectral range: UV--NIR µm: absolute accuracy: <5%). VIS/NIR imaging spectrometer (FOV ≤40°, spectral range 400-1050 nm, iFOV < 1mrad) Imaging IR sensor and remote thermometer (sensor accuracy ±1K) High res digital nadir camera <u>L-band InSAR</u> L-Band frequency (~ 1.25 GHz) Dual-polarized or quad polarized <10° phase sensitivity <5 m horizontal resolution <u>Ground Truth</u> SWE accuracy: 2cm (SWE <20cm), 10% (SWE >20cm) Snow density accuracy: 20 kg/m^3 or 2% Snow depth accuracy: 3 cm Snow temperature: 1°C. Snow grain size: 0.2 mm (<1 mm), 1 mm (1-15 mm)	Field location representing gradients of forest density on relatively flat terrain and location with complex terrain to test all RS techniques. Airborne platform(s) with flexible range and altitude capabilities matching optimum sensing altitudes (e.g.,1000-6000 ft AGL), with capacity for multiple instruments and flight profiles Fully coordinated airborne and in-situ snow surveys at nested scales during the field season Temporal resolution — daily ground observations during airborne observations (at least 2 8hr-flights per week) at least two weeks in winter. Physical, empirical, and/or statistical snow distribution models to scale ground measurements to airborne and satellite remote sensing scales <u>Models</u> Spatial scaling models Radiative transfer and scattering models Snowpack physical models including snow redistribution and interception components Snow physical models (secondary) Hydrology / climate models SWE retrieval algorithms	<u>Ground Obs. Data</u> Ground observation logs and data records Instrument metadata Raw observations, and catalogued and corrected observations, measurement, and calibrations Filtered forest litter snow samples Local meteorological and radiation observations <u>Airborne Data</u> Level 0 raw instrument and engineering data stream for each flight Level 1 radiometric and geometric corrected data (i.e., brightness temperature, TB, backscatter), InSAR phase and coherence Level 2 geophysical parameter data (SWE, albedo, BRDF, HCRF …) Level 3 gridded data integrating airborne and ground measurements for select locations (e.g. SWE values and evolution over the season, albedo vs SWE relationships) Level 4 results from models incorporating L3 data Ancillary satellite data collected during field campaigns <u>Ground-based RS</u> Level 0 raw instrument and engineering data stream

	- Forest structure metrics including tree height, crown radius, and forest density. - Soil moisture, roughness - Short vegetation - Calibration for certain airborne observation - In situ tower radiation and energy balance. Four component radiation (SW, in and out, LW in and out) - Wind speed and direction - Relative humidity - Air temperature - Snow and soil temperature profile - Barometric pressure - Spectral albedo - Ground-based RS to provide time series prior and between airborne RS obs	Microstructure obs. (e.g. SSA from the SnowMicroPenetrometer, SMP, and IceCube) Dielectric obs. (e.g. from SnowFork, Denoth meter) Equipment for soil and short vegetation measurements (pinboard, Hydra Probe Soil Sensor, scoop & oven) Field spectroscopy VSWIR of spectral radiance, spectral irradiance, and spectral albedo Broadband and spectral in situ albedos 3-D Terrestrial Laser Scanner (TLS, e.g. Riegl VZ400 or similar) to characterize stand scale forest structure characteristics within a 300-m diameter area. Portable VIS-NIR field spectrometer Hemispherical photos using a digital camera such as Nikon Coolpix 995 with a levelled fish eye lens, at 50-m intervals and analyzed using Gap Light Analyzer 2.0 Snow samples for filtration to determine forest litter content.		Level 1 radiometric and geometric corrected data (i.e., brightness temperature, TB, backscatter) Level 2 geophysical parameter data <u>Models Data</u> Algorithms for process and ingest of SnowEx data into hydrologic and radiative transfer models Data documenting Improvement of hydro models using SnowEx results.