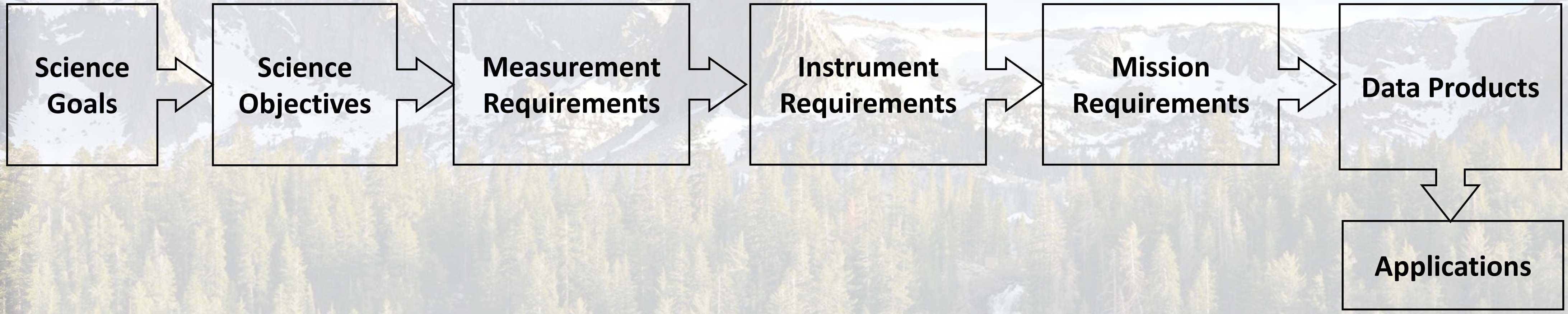
Surface Topography and Vegetation Science and Applications Traceability Matrix

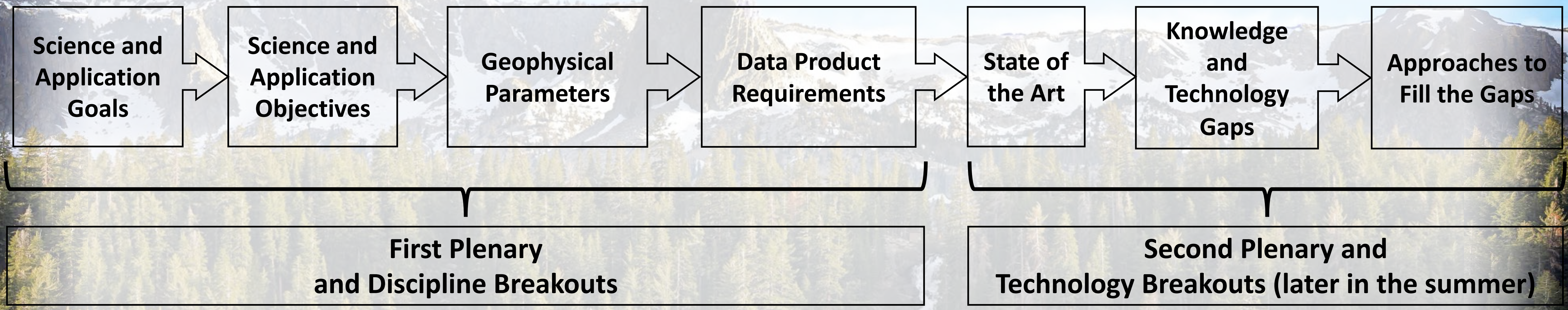
David Harding
STV Incubation Study Technology Lead
NASA Goddard Space Flight Center

Science Traceability Matrix (STM)



- A typical NASA STM focuses on science goals and objectives
- Measurement, instrument and mission requirements are specified for a mission architecture that has already been established
- Often, applications are secondary and are what can be accomplished with the science products
- ***The STV Study is NOT developing this kind of traceability matrix***

Science and Applications Traceability Matrix (SATM)



- Science and applications goals and objectives both contribute to the STV SATM
- The SATM focuses on geophysical parameters, data product requirements and identifying gaps which must be filled before designing an STV mission architecture
- The STV architecture could include multiple sensor types and multiple platforms but ***designing an architecture is outside the scope of the STV incubation study***

STV SATM Components

Science and Application Goals → Science and Application Objectives → Geophysical Parameters →

Science and Applications			
Goals	Objectives	Targeted Observable(s)	Physical Parameter(s) Required

We need your input to develop a thorough and well-justified SATM

Data Product Requirements → **Spatial**

Level 3 or 4 Product	Level 3 or 4 Spatial Requirements Provide three requirements: (1) from the Decadal Survey (NA if not specified), (2) aspirational and (3) threshold						
Product Type	Area of Interest	Coverage (%)	Smallest Feature Resolution (m)	Sampling Distance (m)	Absolute Accuracy	Relative Accuracy (data set internal consistency)	Slope Accuracy (deg)

Data Product Requirements → **Temporal**

Level 3 or 4 Temporal Requirements Provide three requirements: (1) from the Decadal Survey (NA if not specified), (2) aspirational and (3) threshold					
Rate of Change Accuracy (parameter/yr)	Size of Area Observed to Determine the Rate of Change (sq km)	Latency (days)	Repeat Frequency (days)	Repeat Duration (months)	Ancillary Data Required

State of the Art → Knowledge and Technology Gaps → Approaches to Fill the Gaps →

Current Technology Solutions		Identified Gaps		Potential Activities to Close Gaps				
Applicable Sensor Type(s)	Are requirements currently met? Y/N	Scientific Knowledge	Technology Capabilities	Simulations	Experiments	Existing Data Analysis	Instrument Development	Platform Development

SATM Goals and Objectives

Science and Application Goals

- A high-level statement of a compelling need for which height information is fundamental

Science and Application Objectives

- Expressed as a question or stating a purpose
- It is the reason for which physical parameters are measured and products are made
- Making the measurements or products is NOT the objective.

Sources for Goals and Objectives

- Directly mapped from the 2017 Decadal Survey
- Augmented by the STV Study Team
- Incorporating inputs from the science and applications communities **through the on-line questionnaire linked at https://science.nasa.gov/earth-science/decadal-stv**

SATM Geophysical Parameters

- **An attribute of the Earth's surface, independent of the measurement method.**
- **An objective may require more than one geophysical parameter.**
- **Change in these parameters over time is a an important component of the STV SATM.**

Topography (land and ice):

(1) bare Earth (ground with vegetation, structures and snow removed),

(2) highest surface (top of vegetation, structures, snow, ice, water or ground)

and parameters derived from heights

(3) snow depth, (4) sea ice freeboard, (5) drainage networks, (6) stream flow volume, (7) ground water change and (8) structure shapes (e.g., buildings)

Vegetation Structure (terrestrial and shallow water benthic):

(9) height, (10) cover (nadir projected), (11) plant area (summed projected surface area), (12) leaf area, (13) above ground biomass, (14) 3D organization (spatial distribution of foliage, woody material and gaps), (15) rugosity (roughness), (16) structural complexity and (17) stem density

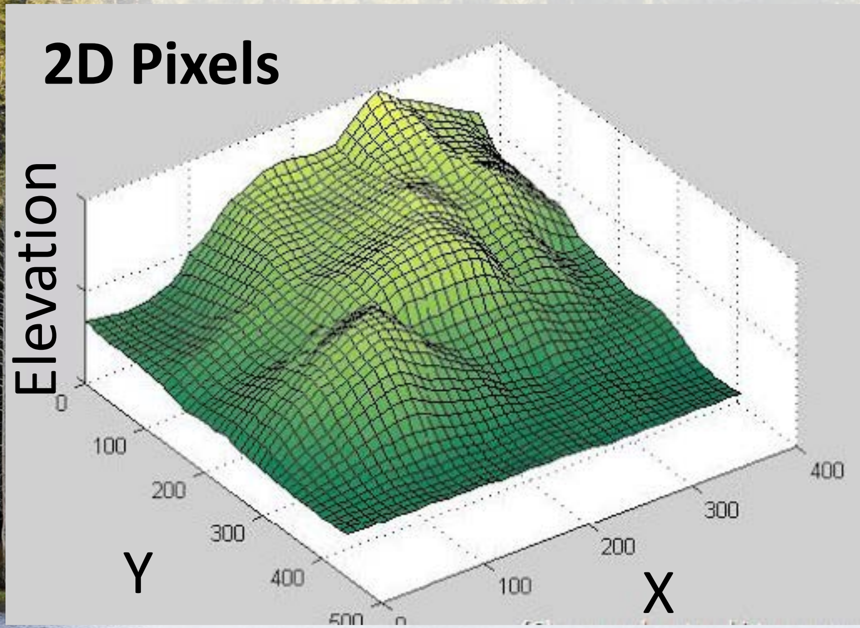
Shallow Water Bathymetry (inland and coastal):

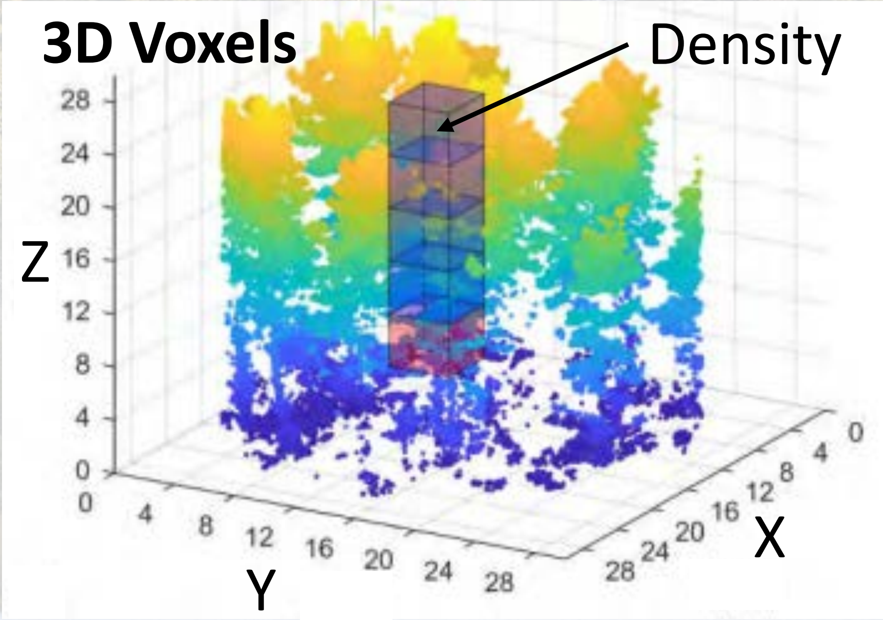
(18) surface height, (19) bottom topography, (20) water depth and (21) wave structure

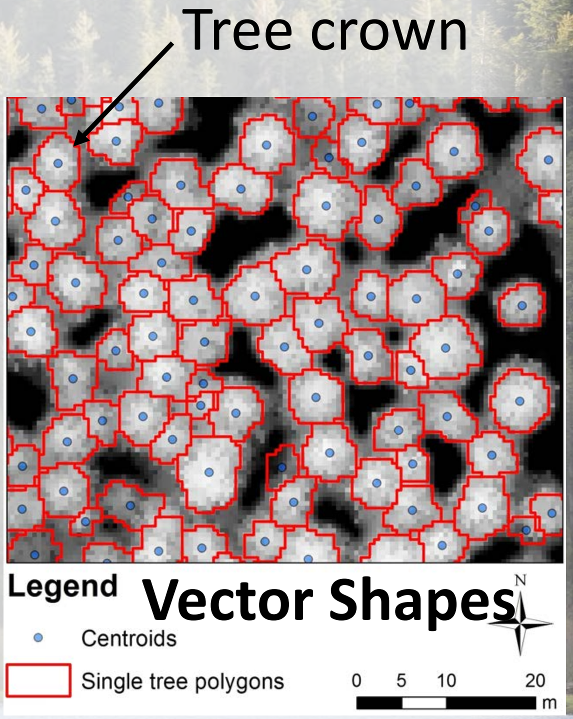
Candidate STV Products

➢ **There are three types of candidate products for representing STV geophysical parameters**

- 2D gridded, contiguous pixels (x,y) (e.g., elevation)
- 3D gridded, contiguous voxels (x,y,z cubes) (e.g., vegetation density)
- 2D or 3D vector shapes (e.g., tree crowns)







Candidate 2D Products

- **Gridded pixel representation of a geophysical parameter**
  - **Directly from measurements of height**

    Digital Terrain Model (DTM) of bare Earth topography

    Digital Surface Model (DSM) of highest surface

    Digital Height Model (DHM = DSM – DTM)

    Sea Ice Freeboard (height above the water)

    Snow Depth

    Shallow Water Depth

    Canopy Crown Depth

    Height or Depth Change (dh/dt)

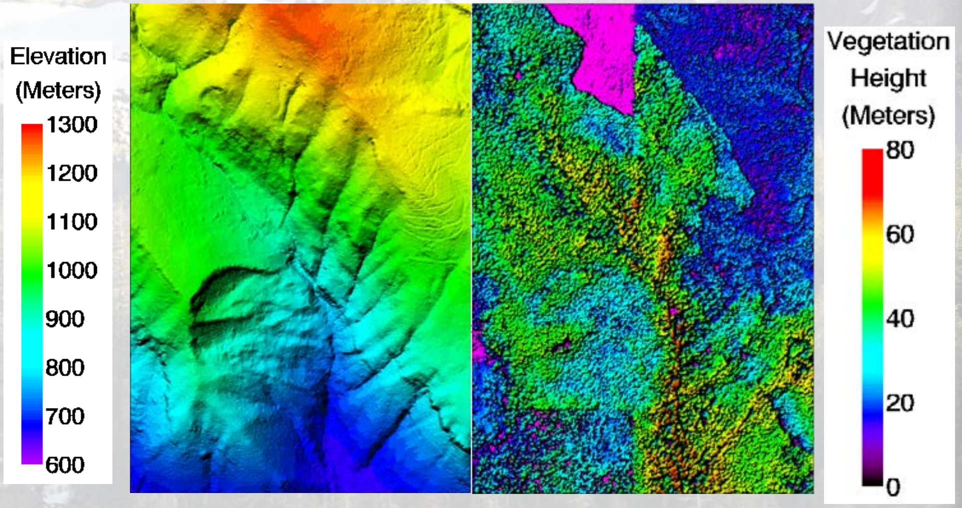
    from repeated measurements

    Shallow Water Wave Structure

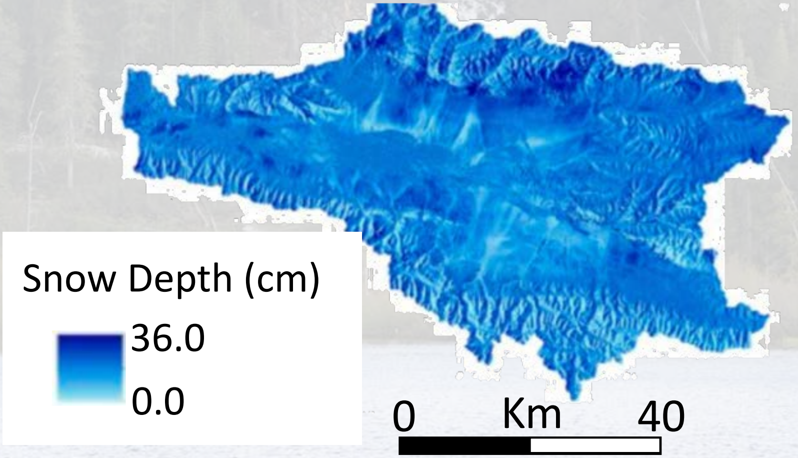
    orientation, amplitude and spacing

DTM shaded relief colored by elevation

DSM shaded relief colored by canopy height



Adapted from D. Harding, 2009, Pulsed Laser Altimeter Ranging Techniques and Implications for Terrain Mapping, CRC Press.



Y. Liu, 2017, Estimating Snow Depth Using Multi-Source Data Fusion Based on the D-InSAR Method and 3DVAR Fusion Algorithm, Remote Sensing.

Candidate 2D Products

- **Gridded pixel representation of a geophysical parameter**
  - **Derived from measurements of height**

    Canopy Cover Fraction (total)

    Plant Area Index (total)

    Leaf Area Index (total)

    Above Ground Biomass (total)

    Structural Complexity (total)

    Surface Rugosity (roughness)

    Stem Density

    Stream Flow Volume

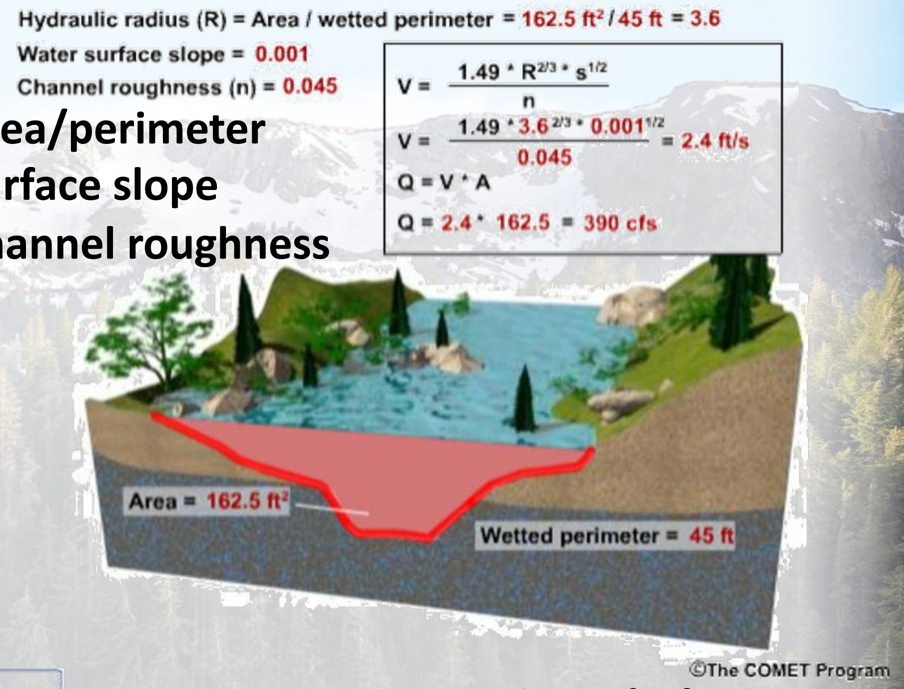
    Ground Water Change

Stream Flow: Manning's Equation

Area/perimeter

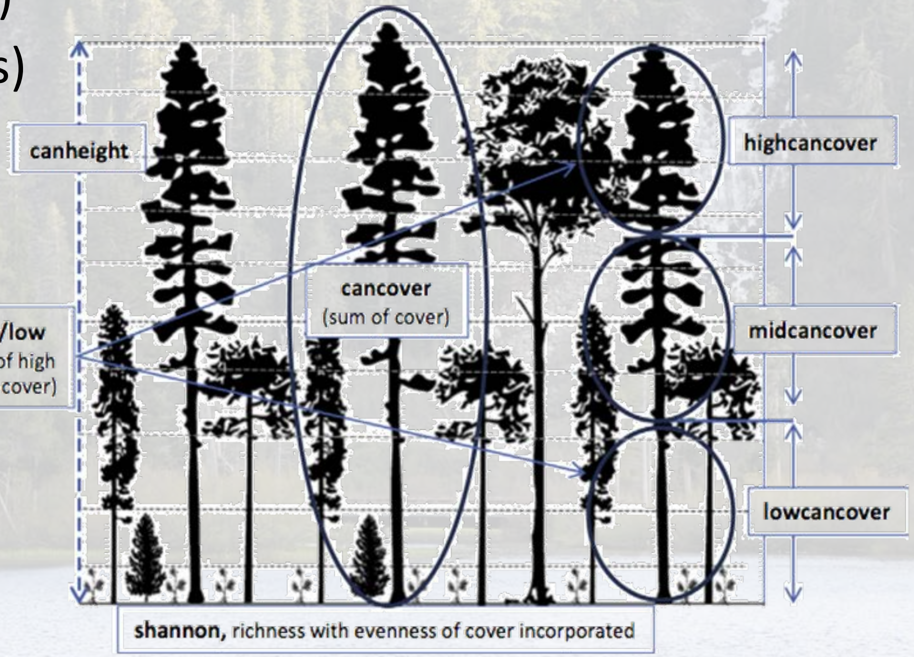
Surface slope

Channel roughness



UCAR, 2005, Basic Hydrologic Science Course: Streamflow Routing, COMET Program.

Structural Complexity



A. Hansen, et al., 2014, Regional-scale application of lidar: Variation in forest canopy structure across the southeastern US, Forest Ecology and Management.

Candidate 3D Products

- **Gridded voxel (cube) representation of a geophysical parameter**
  - **Directly from measurements of height**

    Vegetated and Not Vegetated (gaps)
  - **Derived from measurements of height**

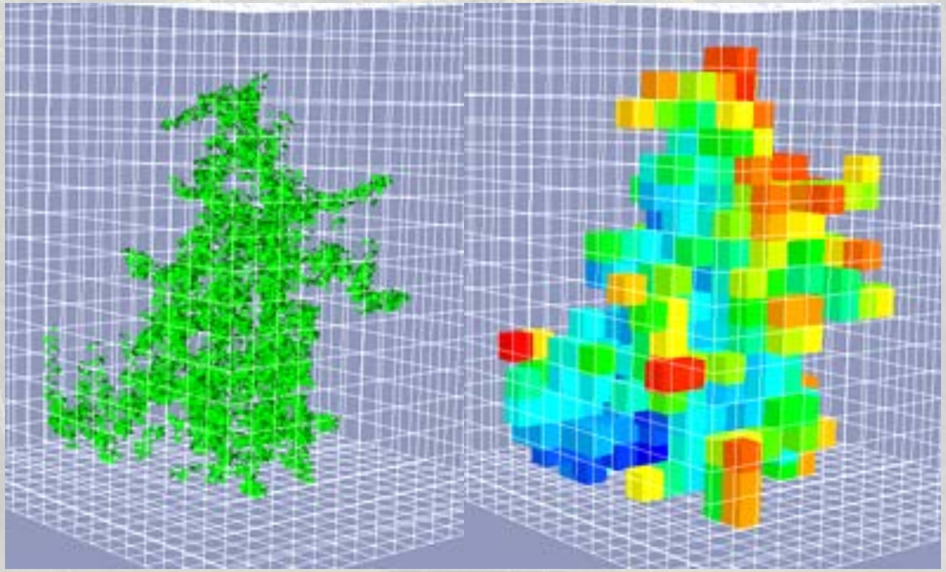
    Canopy Cover Fraction

    Plant Area Index

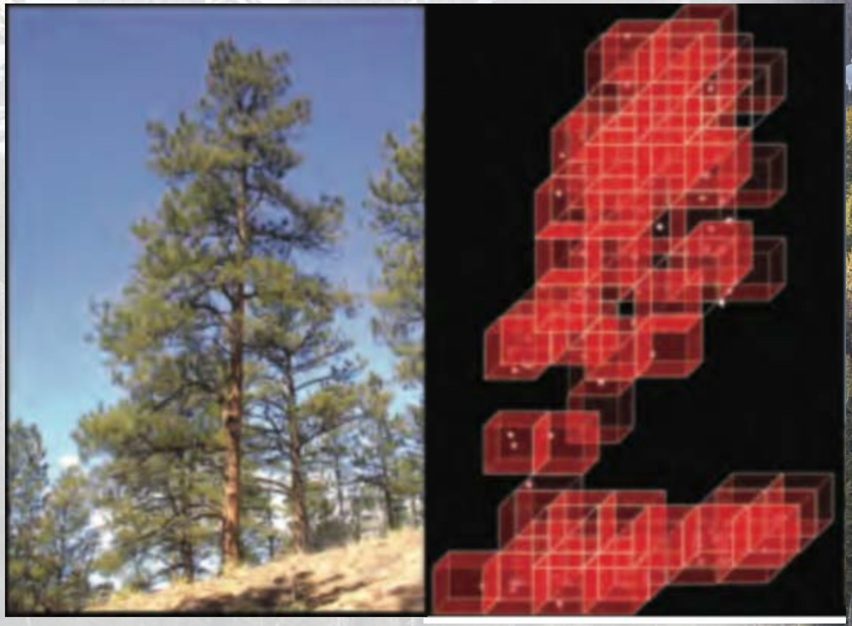
    Leaf Area Index

    Above Ground Biomass

    Structural Complexity



Canopy voxel representation in RAPT model



J. Stoker, 2009, Volumetric visualization of multiple-return LIDAR data using voxels, PE&RS.

Candidate Vector Products

- **Vector representation of a geophysical parameter**
  - **Derived from measurements of height**

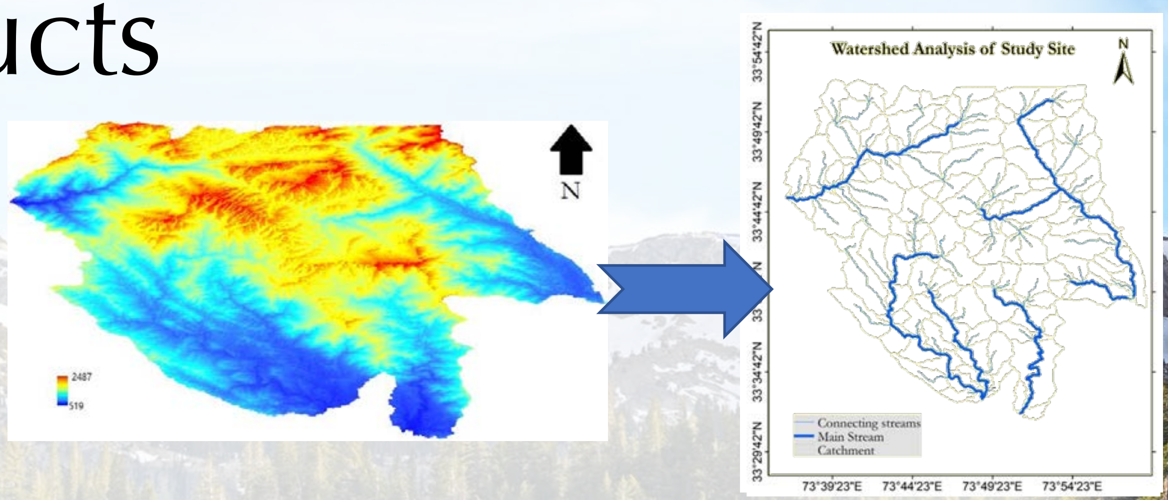
    Drainage networks

    Tree or shrub crowns

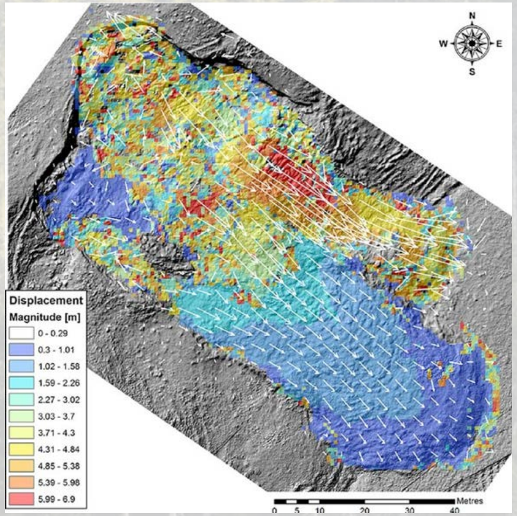
    Structures (buildings)

    Displacement vectors from repeated measurements

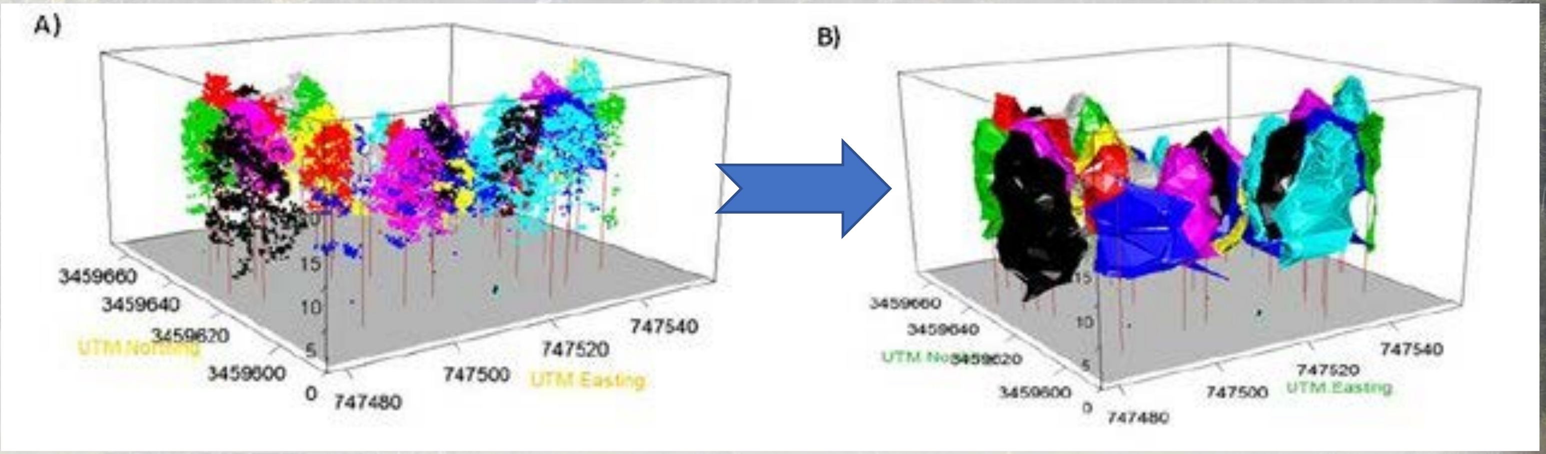
    Velocity vectors from repeated measurements



R. Imram et al., 2019, Delineation of Drainage Network and Estimation of Total Discharge using Digital Elevation Model, International Journal of Innovations in Science & Technology



A. Lucieer, et al., 2013, Mapping landslide displacements using Structure from Motion, Progress in Physical Geography



C. Silva et al., 2014, Extracting Individual Trees and Lidar Metrics Using a Web-Lidar Forest Inventory Application, Remote Sensing and GIS Applications

Product Requirement Context

- **Seeking your input in the questionnaire available at the link on the STV web site**
  - https://science.nasa.gov/earth-science/decadal-stv
- **Applicability of requirements**
  - The requirements must be traceable to objectives that will be conducted at regional to global scales.
  - Local studies that are not a component of regional to global studies are out of scope.
  - Requirements are **NOT** necessarily the attributes of the best data you have used to conduct local science or applications studies; **can data of lesser quality meet the objectives at regional to global scales**?
  - Requirements should be justified based on data analyses, sensitivity studies or modelling in published literature and/or expert consensus reported in community documents, and the sources should be cited.
  - **For requirements where no justification is available, no requirements should be stated.** This will identify knowledge gaps which need to be filled through the work of the STV Study Team and through future NASA investments.

Product Requirement Categories

- **Three types of requirements are being documented in the STV SATM**
  - **From the Decadal Survey**

    Requirements that are specified in the 2017 Decadal Survey.

    These are limited and in some cases are inconsistent.
  - **Aspirational from Study Team and Community Input**

    STV Study requirements that would enable **dramatic** science and applications advances.

    What you would really like to have in the next decade for regional to global studies.
  - **Threshold from Study Team and Community Input**

    STV Study requirements that would enable **important** science and applications advances.

    What would be better than is now available or is expected in this decade from planned missions.
  - **Do not limit your aspirational and threshold requirements by what you think technology can accomplish, now or in the future.**
  - **This is your opportunity to challenge NASA and technologists to make significant advances in capabilities for the coming decade.**
  - **But do keep in mind that these are requirements for regional to global studies.**

Product Spatial Requirements (1 of 2)

- **Area of Interest**
  - The area(s) that need to be observed to meet the objective:
    - Global or specified regions and/or features.
- **Coverage**
  - Percentage of the area of interest that needs to be observed to meet the objective.
  - Is some form of spatial sampling sufficient or is wall-to-wall mapping required?
- **Feature Resolution**
  - The horizontal and vertical dimensions of the smallest feature that must be discerned.
- **Sampling Distance**
  - In gridded products, the size of independent pixels (x,y) or voxels (x,y,z).
    - Typically, the horizontal and vertical sampling distances should be 1/3 of the smallest feature to resolve them.
  - For vector products, it is difficult to define but notionally it is the average distance between nodes.

Product Spatial Requirements (2 of 2)

- **Absolute Accuracy**

  Systematic and random offsets in the horizontal and vertical* dimensions with respect to the true locations in a defined reference frame.

- **Relative Accuracy (data set internal consistency)**

  Random offsets in the horizontal and vertical* dimensions with respect to other locations in the same data set.

- **Slope Accuracy (when applicable to an objective)**

  Systematic and random differences of slope steepness (amplitude) and direction (azimuth) with respect to the true slope steepness and direction

* **For parameters whose values are not a vertical dimension (e.g., canopy cover, plant area, biomass, slope amplitude and azimuth), the accuracies are with respect to horizontal location and the parameter value.**

Product Temporal Requirements

- **Repeat Frequency**

  How often does the parameter need to be measured?

  Is the repeat frequency time dependent (e.g. fast repeats immediately following an event then decreasing in frequency over time)?

- **Repeat Duration**

  For how long does the parameter need to be measured (e.g. what is the typical duration of change in response to an event)?

- **Rate of Change Accuracy (when applicable to an objective)**

  The difference with respect to the true rate of change, accounting for systematic and random errors.

- **Latency**

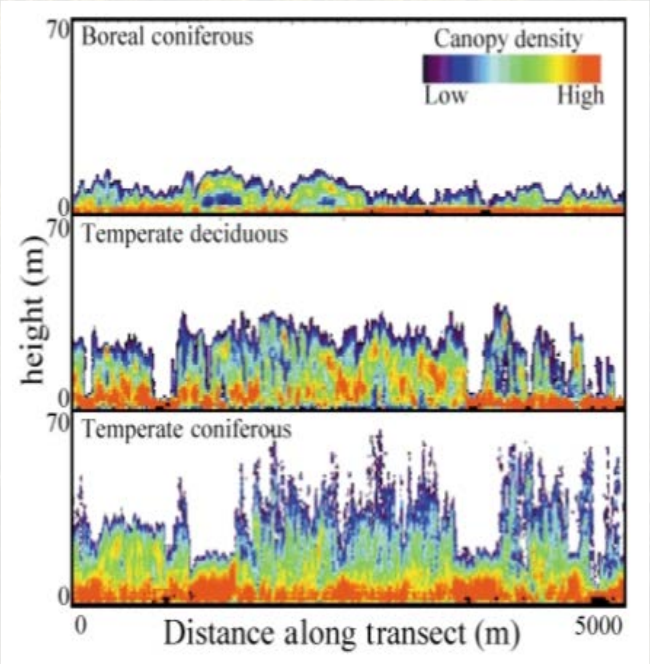
  Time from the measurement of a parameter to the public delivery of the product.

Ancillary Data Requirements for STV Products

- **What additional information is required to augment the measurements of surface heights in order to fully meet an objective?**

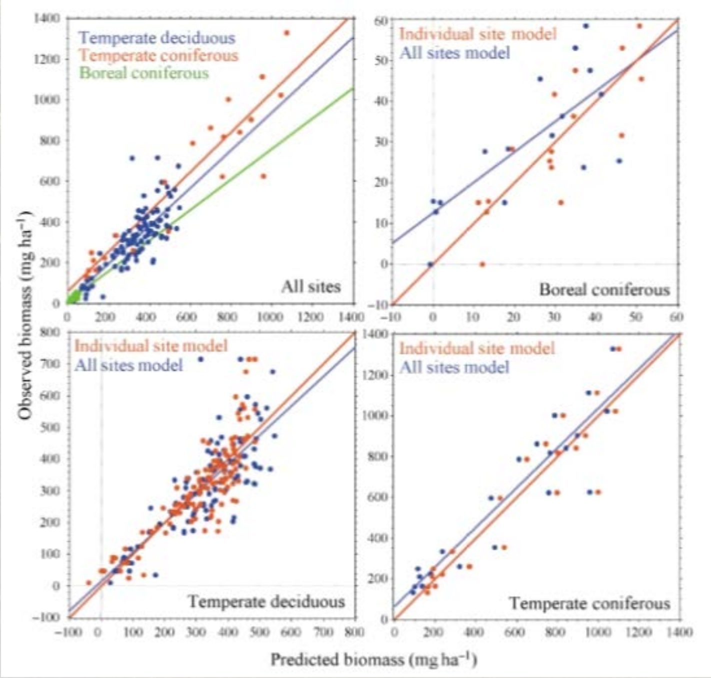
  For example, biome type and a model relating canopy height and density to biomass

Canopy Height and Density Products



Biome Type and Model

Derived Biomass Product



M. Lefsky, et al., 2002, Lidar remote sensing of above-ground biomass in three biomes, Global Ecology & Biogeography

Additional STV Science and Applications Benefits

- **There are data products to which STV height measurements will contribute through fusion with other essential data and through modelling**
- **However, height measurements are only a subset of the required inputs**
- **Examples include:**
  - **Magma chamber inflation and deflation**
  - **Fault stress accumulation**
  - **Snow Water Equivalent (SWE) in snow pack**
  - **Soil moisture**
  - **Evapotranspiration (ET)**

ET inputs from height measurements

Canopy structure for precipitation through-fall

Snow depth for SWE

Digital Terrain Model

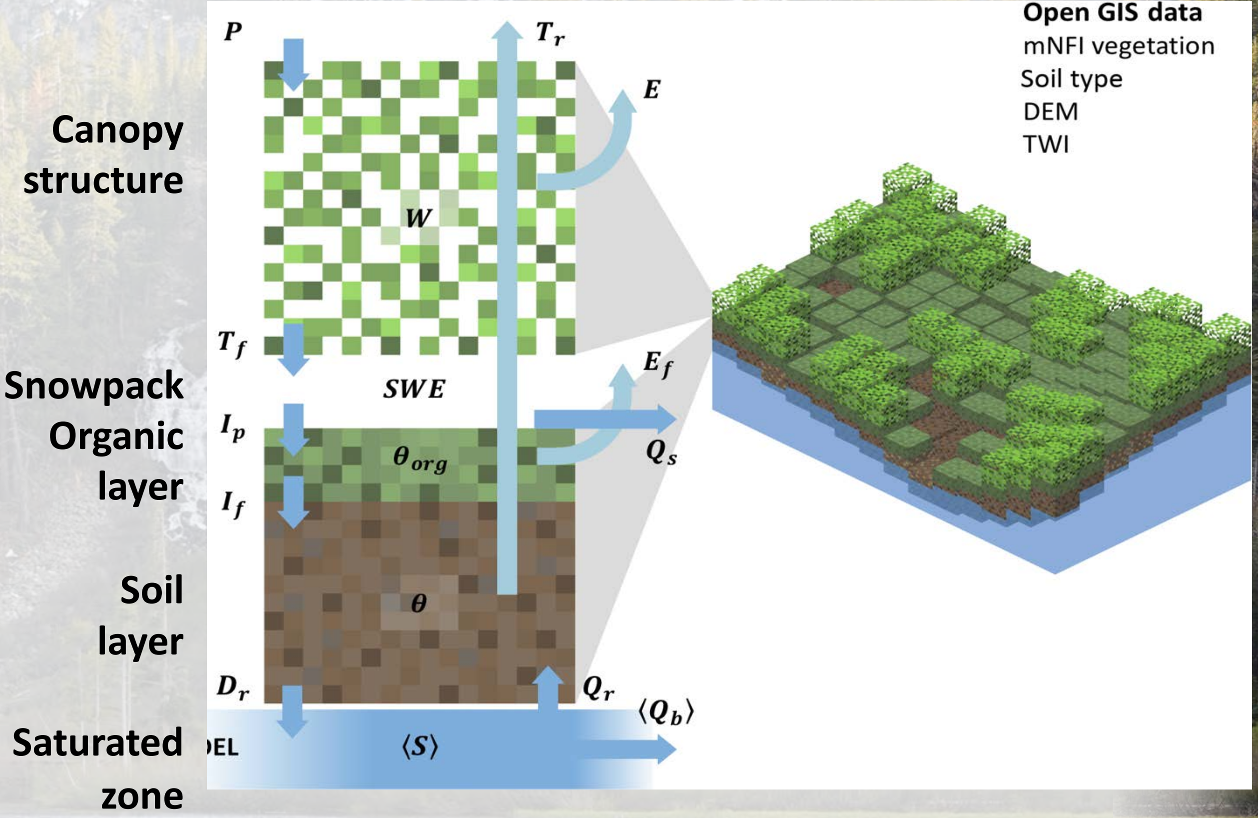
- *Catchment area*
- *Surface slope*

Non-STV ET inputs

Vegetation and soil types

Precipitation

Water infiltration, drainage and runoff models



S. Launiainen, et al., 2019, Modeling boreal forest evapotranspiration and water balance at stand and catchment scales: a spatial approach, Hydrology and Earth System Sciences