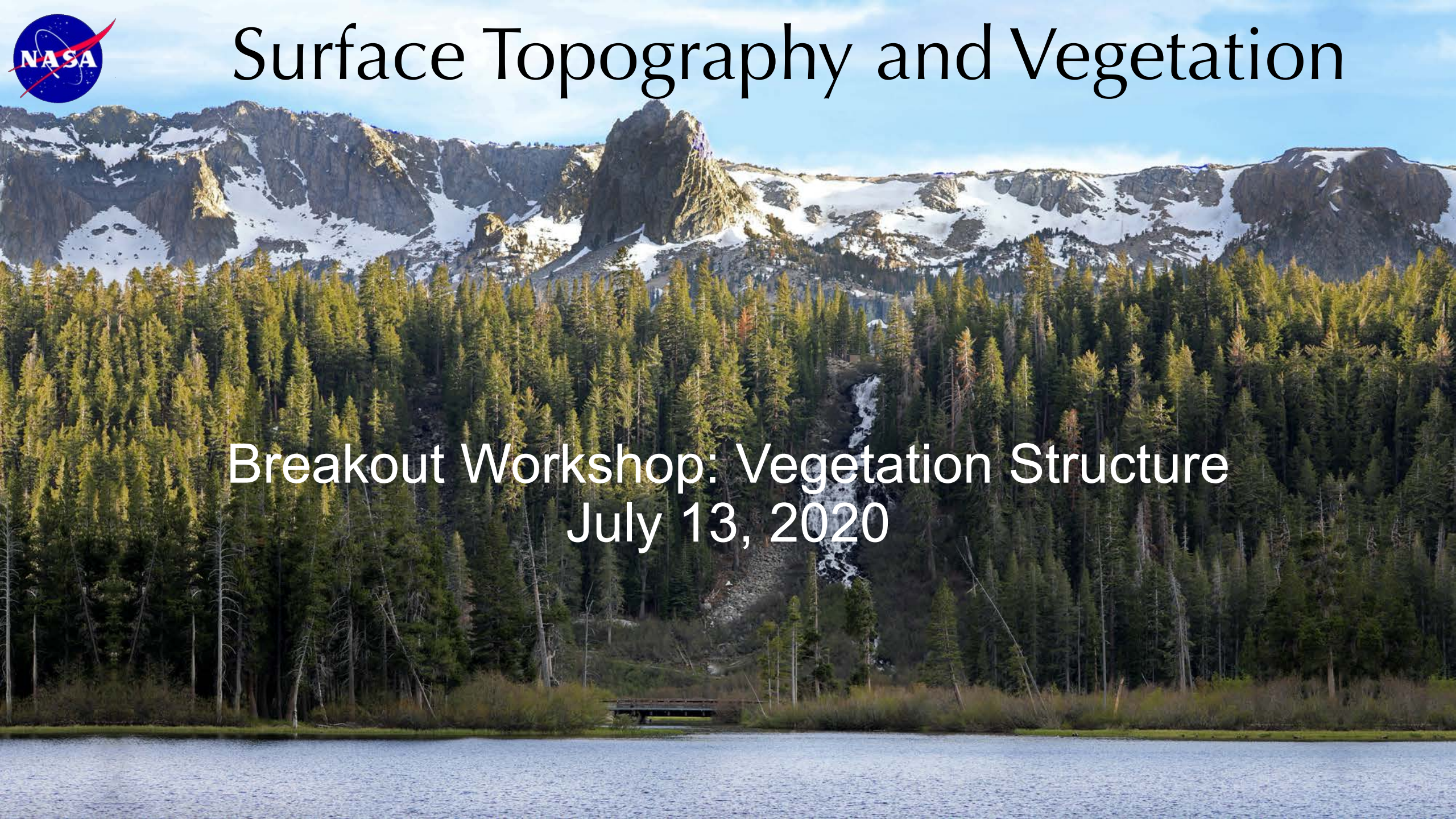


Surface Topography and Vegetation

Breakout Workshop: Vegetation Structure
July 13, 2020

Agenda

8:15am (PT) / 11:15am (ET)	Welcome	
10min	Introduction, SATM process	Konrad Wessels
	Science and Application Objectives: Introduction and feedback from community	
15min	1. Ecosystem structure function and Biodiversity	Konrad Wessels
20min	2. Carbon accounting, biomass, fluxes, sinks	Sassan Saatchi
20min	3. Forest Ecosystems, Agroforestry, Commercial forestry, Deforestation monitoring	Jon Ranson / Robert Treuhaft
15min	4. Wildfire	Cathleen Jones
10min	5. Agriculture	Cathleen Jones
10min	6. Wetland monitoring	Cathleen Jones
15min	Break	
20min	SATM process and terminology	Konrad Wessels / David Harding
30min	Examples of SATM inputs for example questions	Konrad Wessels, others
10min	Introduction to survey for SATM – pdf form	David Harding

10:00am/ 1:00pm

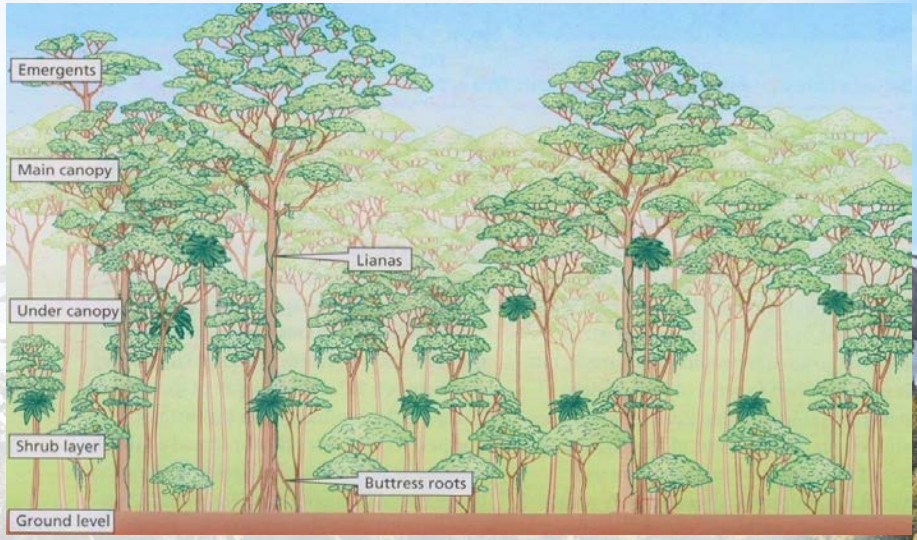
STV study objectives

- STV incubation seeks observing system architectures utilizing emerging sensor 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.
- Incubation: advance technology readiness for high priority Target Observables during the next decade (2027-2037)

STV study Objective: Vegetation Structure

- Identify science and application needs and measurement gaps for: High-resolution vegetation structure to **significantly improve the understanding of ecosystems**, including carbon stocks and fluxes, and relationships between biodiversity and habitat
- Expand the Science questions and measurement needs expressed in DS.
- Breakout session and survey objective: To collect community input for the study team about science questions and application needs, and data product requirements.
- Seek clear **justification** of what products are needed to do your science and applications
- **Science gains** from products

Vegetation structure



- Definition (DS): Spatial distribution of plants and their components on land, and of aquatic biomass.
- Definition: 3D Configuration of above ground vegetation
- Veg structure has vertical and horizontal (spatial) components
- Measurement of vertical component of vegetation structure is an observation gap.

Vegetation Structure

Science and Application Objectives:

- Ecosystem structure and function
- Biodiversity, Habitat structure and its response to disturbance
- Carbon accounting
- Biomass inventory, dynamics and monitoring
- Forest resources management, agroforestry, commercial forestry, deforestation monitoring
- Wildfire, fuel, risk and post-fire recovery
- Agriculture
- Wetland monitoring and management

Decadal Survey to STV incubation study

- Addressing not only TO-20 STV, but also T-22 – “Terrestrial Ecosystem Structure”.
- We are addressing vegetation structure of TO-20 (STV) and TO-22 together, because they address overlapping Objectives and biophysical parameters.

DS Target Observables

TO-20 Surface Topography and Vegetation	• Bare surface land topography • Ice topography • Vegetation structure • Shallow water bathymetry	H	2c		2b, 3c, 4b, 4d
		W		3a	
		E	1b		1e
		C	1c		8f
		S	1a, 1b, 3a, 3b, 4a	1c, 2b, 2c	1d, 4b, 4c, 6b, 7a

Targeted Observable	Science and Applications Summary	Science/Applications Priorities by Panel[3]			
			MI	VI	I
TO-22 Terrestrial Ecosystem Structure	• Forest 3D canopy height/structure and aboveground biomass • Changes in aboveground carbon stock from processes such as deforestation and forest degradation	H			3c
		W			
		E	1b, 3a		1e, 4a, 5a, 5b, 5c
		C	2d		3c, 8f
		S			4c

Decadal Survey to STV incubation study

- Regional to Global – in scope. Local very high res – not in scope.
- Gaps in knowledge about product requirements need to be identified – not just guessed.
- This workshop focusses only on the science question, biophysical parameters needed and the properties of the data products – does not address the measurements or sensors.

Decadal Survey to STV incubation study

- User needs influenced by recent experience with specific data products. E.g. airborne LiDAR CHM, SAR, recently GEDI data.
- But what do we really need to address our science questions and applications as various scales?
- Default answer: 1m CHM everywhere – not yet feasible
- Need measurement of vertical structure

Vegetation Structure

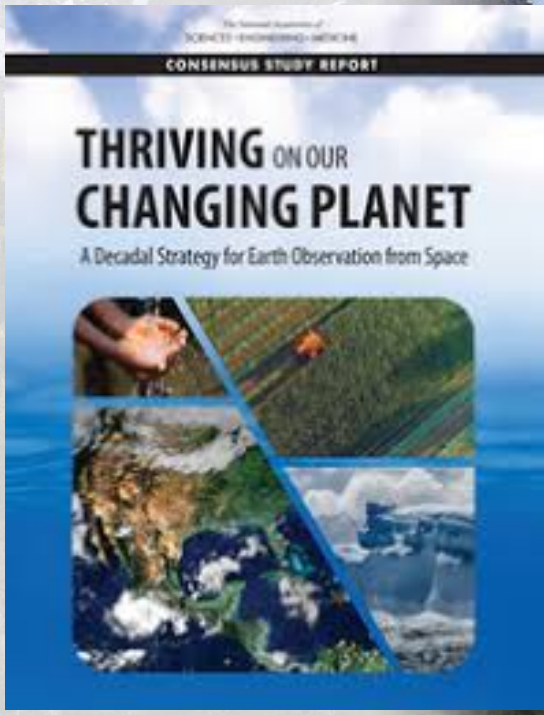
Overarching Decadal Survey Goals:

1. What are the structure, function, and biodiversity of Earth's ecosystems, and how and why are they changing in time and space? (E-1) (most important)

2. What are the fluxes (of carbon, water, nutrients, and energy) within ecosystems, and how and why are they changing? (E-3) (most important)

3. How is carbon accounted for through carbon storage, turnover, and accumulated biomass? (E-4) (most important)

4. Are carbon sinks stable, are they changing, and why? (E-5) (most important)



Science and Application Goals and Objectives

Science and Application Goals

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

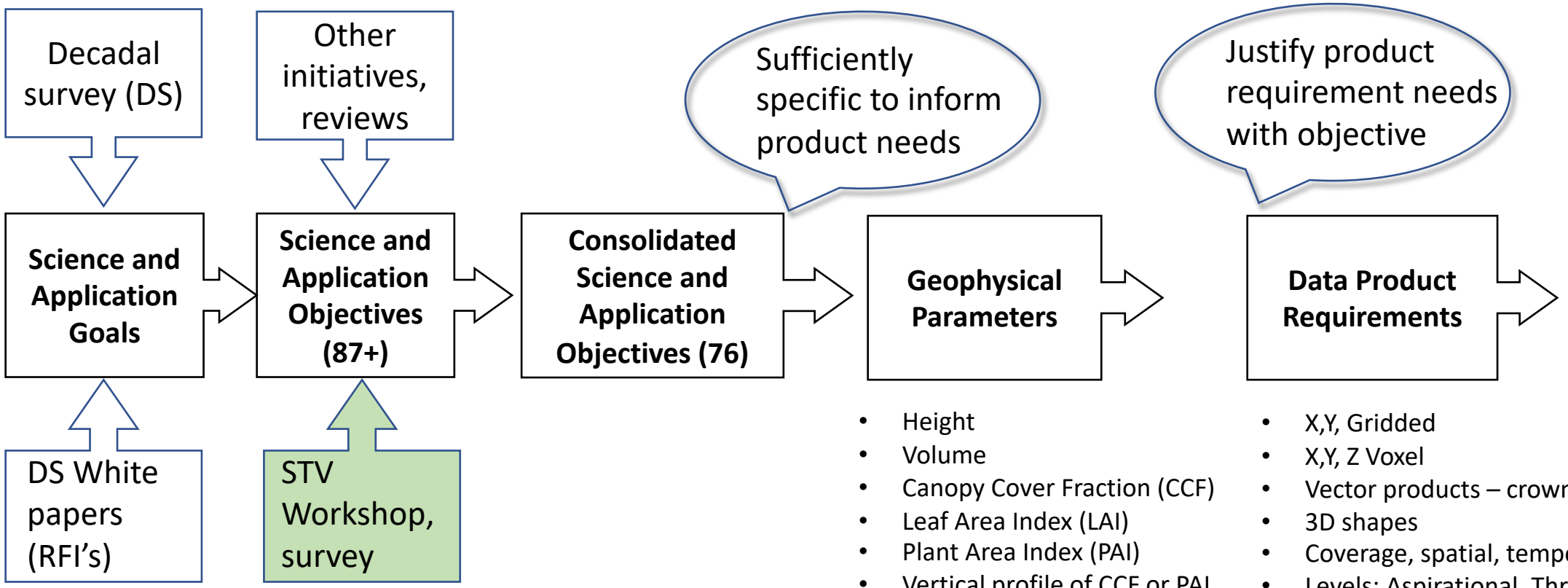
Science and Application Objectives

- 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.**
- **Sufficiently specific to inform product needs**
- **Enough diverse questions to inform comprehensive SATM**

Sources

- Directly mapped from the 2017 Decadal Survey
- Augmented by the STV Study Team incorporating inputs from the science and applications communities

STV SATM Process: Veg structure



- Height
- Volume
- Canopy Cover Fraction (CCF)
- Leaf Area Index (LAI)
- Plant Area Index (PAI)
- Vertical profile of CCF or PAI
- Structure diversity
- Biomass
- Tree crowns
- Stem density
- Gap frequency and size

- X,Y, Gridded
- X,Y, Z Voxel
- Vector products – crowns
- 3D shapes
- Coverage, spatial, temporal
- Levels: Aspirational, Threshold

Vegetation Structure

Overarching Decadal Survey Goals + Expanded:

E-1. What are the structure, function, and biodiversity of Earth's ecosystems, and how and why are they changing in time and space? (E-1) (most important)

- How long can Earth's ecosystems sustain their functions as they are modified by climate and human activities?
- How will water and food security be affected as climate changes and human consumption intensifies; how will they respond to various policies aimed at adapting to and mitigating these effects?
- Biodiversity and ecosystem sustainability are changing as a result of human alterations to the landscape. What are the consequences for human well-being?

Vegetation Structure

Science and Application Objectives : (see list emailed)

DS Goal E-1. What are the structure, function, and biodiversity of Earth's ecosystems, and how and why are they changing in time and space? (E-1) (most important)

- E-1b1 What is the relationship between ecosystem structure and function?
- E-1b2 How is ecosystem structure and function being modified by human activities and climate change?
- E-1b3 How is climate change effecting the structure of boreal forests?
- E-1b5 What are the consequences of significant changes of vegetation structure on existing ecosystem services?
- E-1b6 Are there critical thresholds in biophysical metrics, that, once crossed, lead to long-term or irreversible change?
- E-1b7 Are global savannas gaining or losing trees vs. shrubs?
- E-1b8 What is the impact of increasing CO2 on forest structure and biomass?

Vegetation Structure

Science and Application Objectives :

DS Goal E-1. What are the structure, function, and **biodiversity** of Earth's ecosystems, and how and why are they changing in time and space? (E-1) (most important)

- High-level Goal: What observations are required to monitor globally the widespread and accelerating loss, degradation and redistribution of biodiversity and habitat associated with changes in structure and function of vegetated landscapes?
- E-1f1 What is the relationship between vegetation structure and biodiversity at various scales? (Structural heterogeneity - MacArthur & MacArthur 1961)
- E-1f2 How are changes to 3D habitat structure affecting biodiversity, especially in and around protected areas?
- E-1f4 How do we identify suitable habitat for specific target species (e.g. endangered spp.)

Vegetation Structure

Science and Application Objectives :

DS Goal E-1. What are the structure, function, and **biodiversity** of Earth's ecosystems, and how and why are they changing in time and space? (E-1) (most important)

- E-1f6 What is the impact of forest degradation (selective logging and fragmentation) on habitat structure and its ability to maintain biodiversity?
- E-1f10 What is the relationship between biodiversity and canopy gap size, frequency and their dynamics?
- E-1f12 How do individual tree crowns and canopy strata control seed dispersal and biodiversity maintenance?

Science Questions and Application Objectives

Science questions and Application Objectives

1. Ecosystem structure function and Biodiversity: Konrad Wessels

2. Carbon accounting, biomass, fluxes, sinks: Sassan Saatchi

3. Forest Ecosystems, Agroforestry, Commercial forestry, Deforestation monitoring: Jon Ranson / Robert Treuhaft

4. Wildfire: Cathleen Jones

5. Agriculture: Cathleen Jones

6. Wetland monitoring: Cathleen Jones

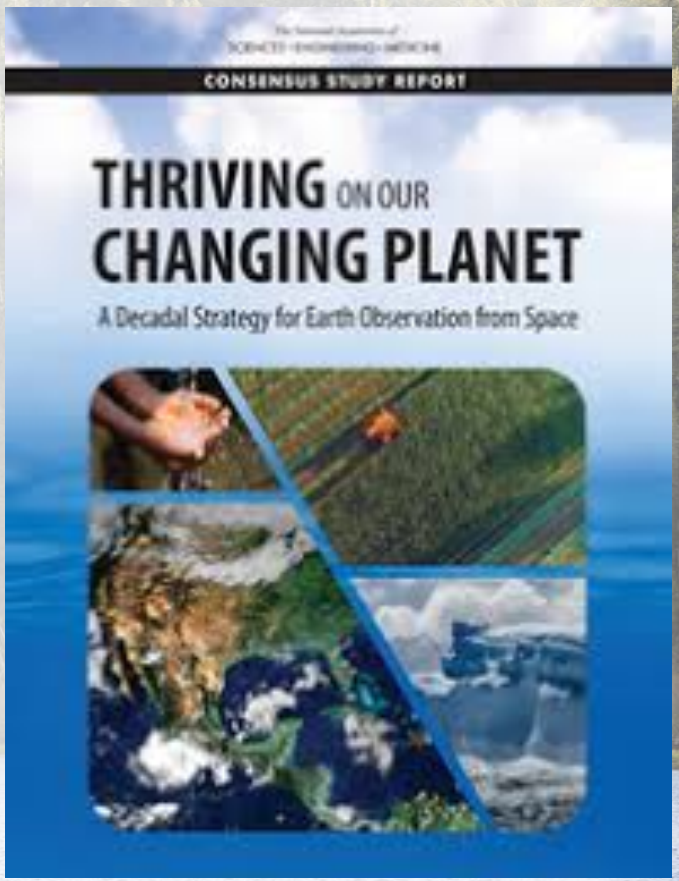
Vegetation Structure Breakout

Carbon accounting, biomass, fluxes, sinks

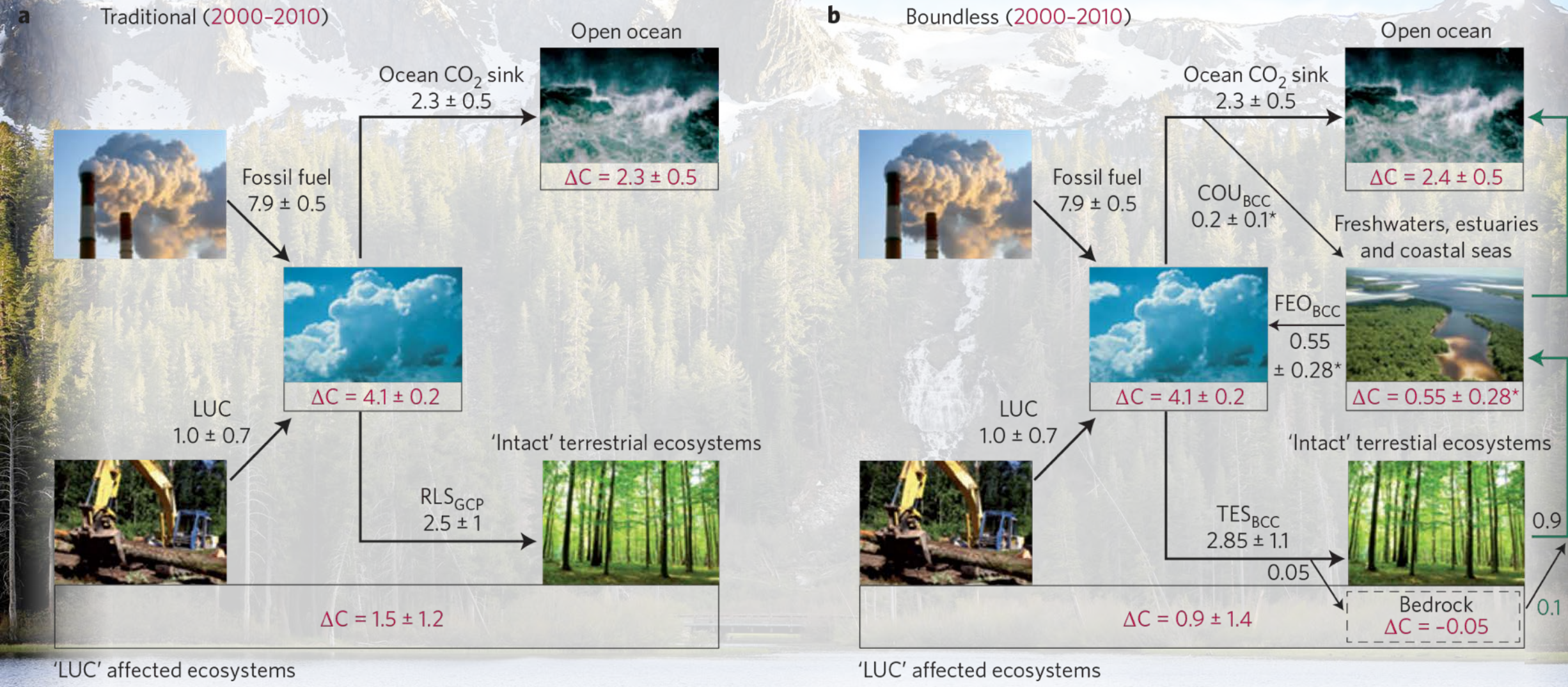
Sassan Saatchi

Vegetation Structure

Science and Applications Questions		Highest Priority Measurement Objectives (MI=Most Important, VI=Very Important)
E-1	**Ecosystem Structure, Function, and Biodiversity.** What are the structure, function, and biodiversity of Earth's ecosystems, and how and why are they changing in time and space? ("Structure" is the spatial distribution of plants and their components on land, and of aquatic biomass. "Function" is the physiology and underpinning of biophysical and biogeochemical properties of terrestrial vegetation and shallow aquatic vegetation.)	**(VI) E-1a.** Quantify the distribution of the functional traits, functional types, and composition of terrestrial and shallow aquatic vegetation and marine biomass, spatially and over time. **(MI) E-1b.** Quantify the three-dimensional (3D) structure of terrestrial vegetation and 3D distribution of marine biomass within the euphotic zone, spatially and over time. **(MI) E-1c.** Quantify the physiological dynamics of terrestrial and aquatic primary producers. Two additional objectives associated with this question were ranked Important.
E-2	**Fluxes Between Ecosystems, Atmosphere, Oceans, and Solid Earth.** What are the fluxes (of carbon, water, nutrients, and energy) *between* ecosystems and the atmosphere, the ocean, and the solid Earth, and how and why are they changing?	**(MI) E-2a.** Quantify the fluxes of CO_2 and CH_4 globally at spatial scales of 100-500 km and monthly temporal resolution with uncertainty <25% between land ecosystems and atmosphere and between ocean ecosystems and atmosphere. Two additional objectives associated with this question were ranked Important.
E-3	**Fluxes Within Ecosystems.** What are the fluxes (of carbon, water, nutrients, and energy) *within* ecosystems, and how and why are they changing?	**(MI) E-3a.** Quantify the flows of energy, carbon, water, nutrients, and so on sustaining the life cycle of terrestrial and marine ecosystems and partitioning into functional types. One additional objective associated with this question was ranked Important.
E-4	**Carbon Accounting.** How is carbon accounted for through carbon storage, turnover, and accumulated biomass? Have all of the major carbon sinks been quantified, and how are they changing in time?	Two objectives associated with this question were ranked Important.
E-5	**Carbon Sinks.** Are carbon sinks stable, are they changing, and why?	Three objectives associated with this question were ranked Important.



Global Sources and Sinks of Carbon



Regnier et al. 2013

Global Sources and Sinks of Carbon

Le Quéré et al., 2018

GCP, 2018


87%
9.4 GtC/yr

13%
1.5 GtC/yr

Sources

≈

5%
0.5 GtC/yr

Budget Imbalance

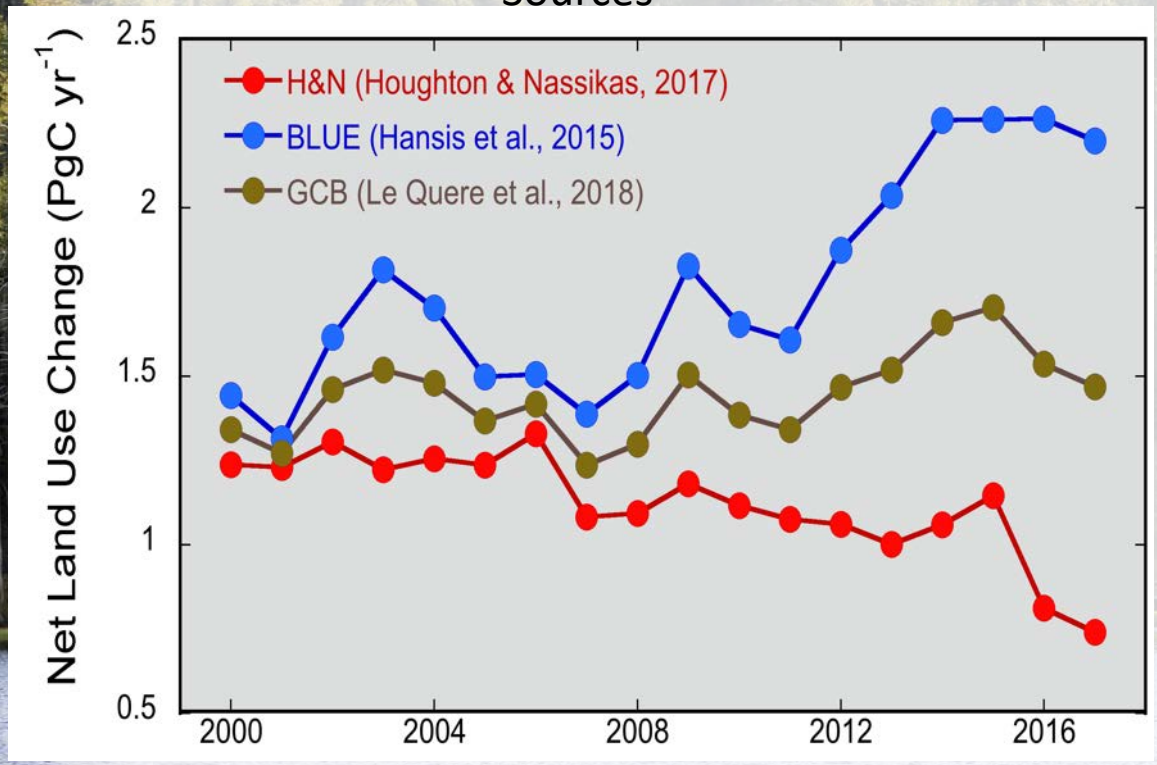


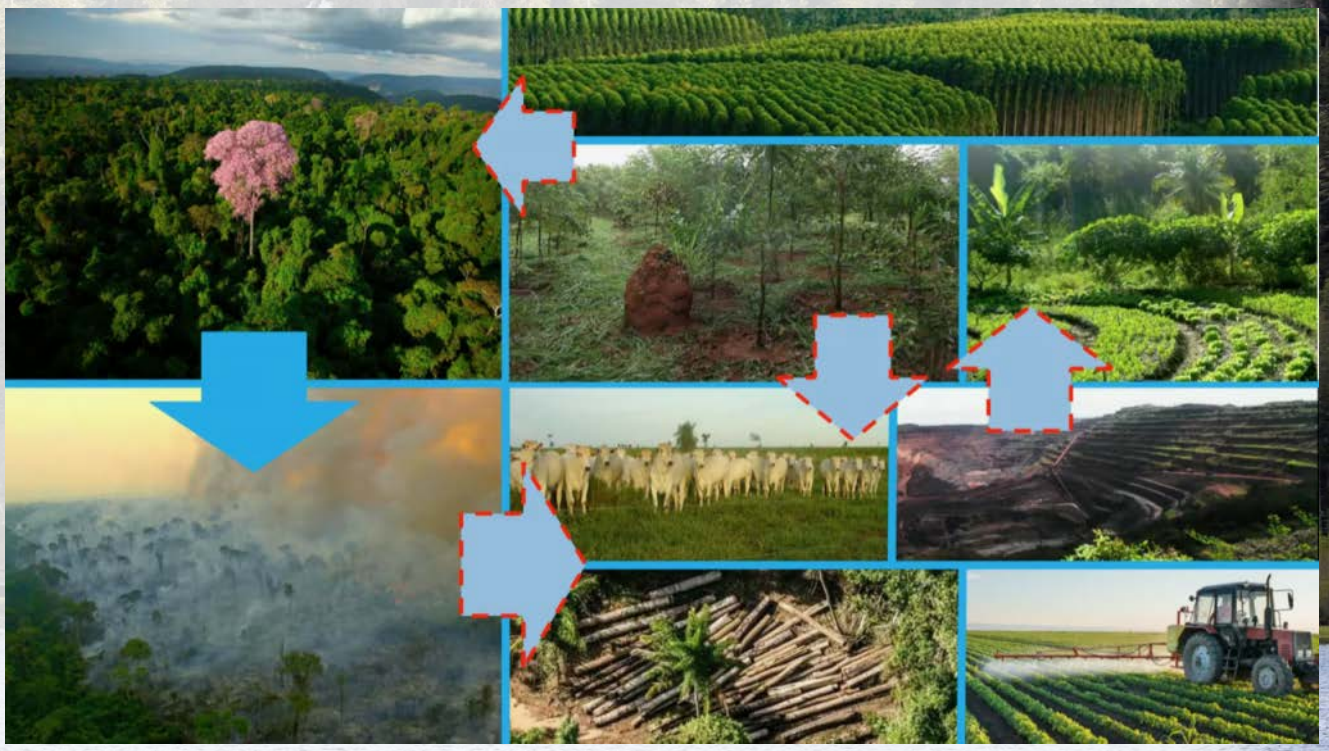
44%
4.7 GtC/yr

29%
3.2 GtC/yr

22%
2.4 GtC/yr

Sinks





E-3 Fluxes within Ecosystems. What are the fluxes (of carbon, water, nutrients, and energy) within ecosystems, and how and why are they changing?

E-3a. How do changes of vegetation structure from disturbance and recovery impact the fluxes of carbon and water?

E-3b: How does structural stability (of ecosystem impact the exchange of carbon and water?

E-3c: How do vegetation gross and net primary productivity depend on landscape variations of vegetation structure?

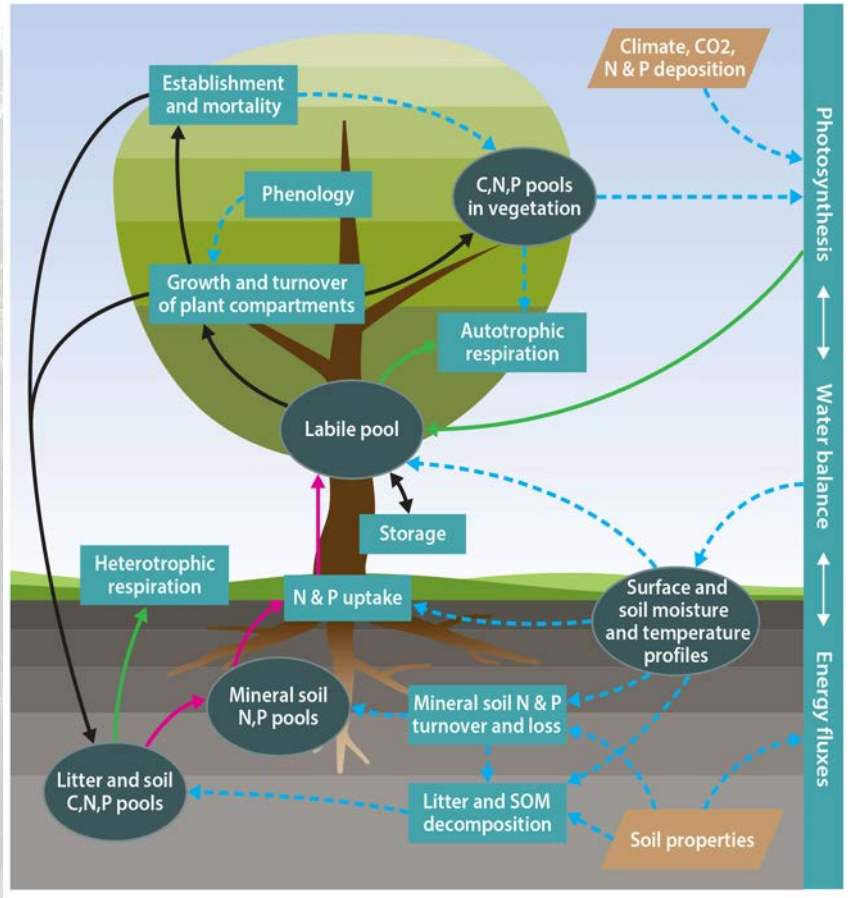
E-3d: What is the impact of biomass burning (gaps, tree mortality, biomass loss) on carbon pools and fluxes within the ecosystem?

E-3e: Does vegetation structure (height, LAI profile, tree distribution) control the flow of water, energy, and carbon?

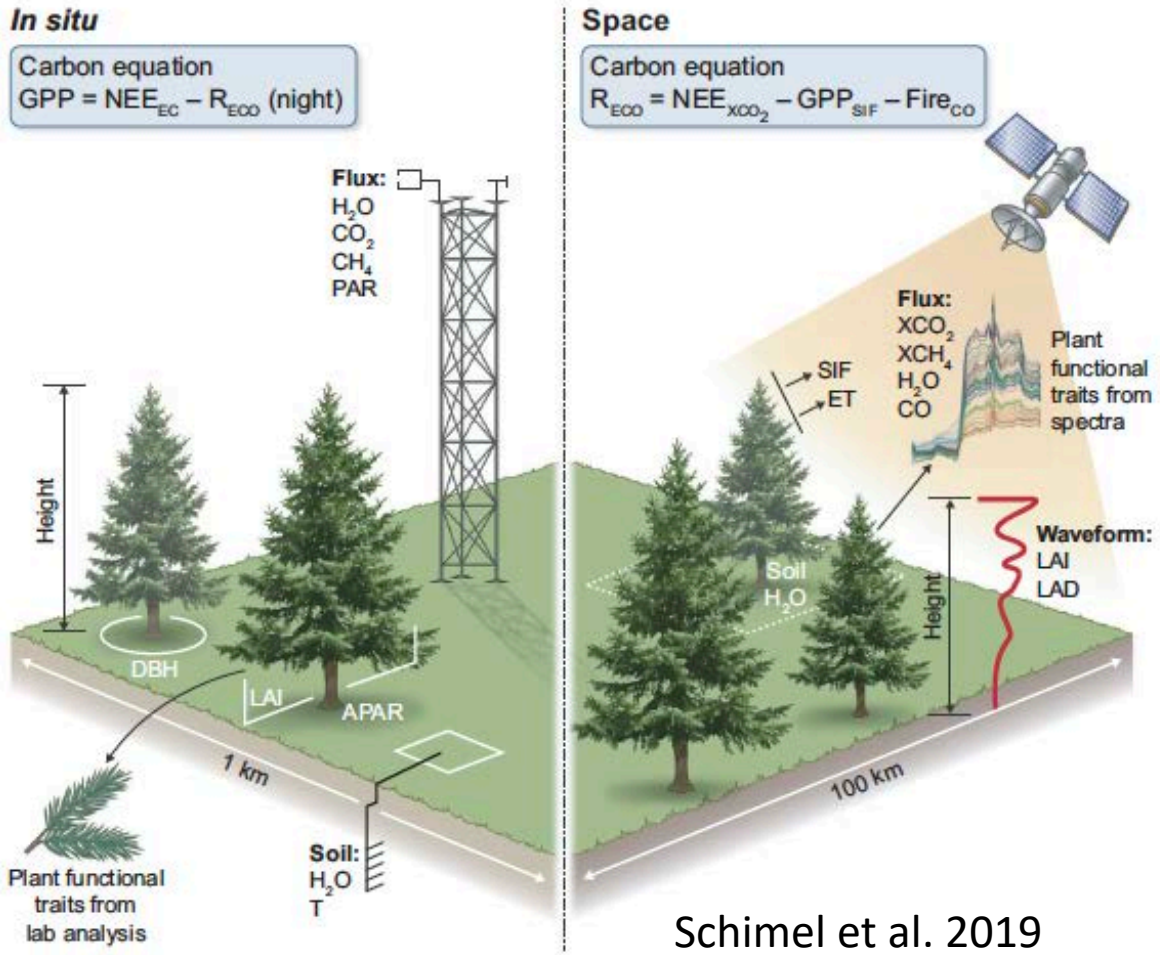
E-3f: To what extent does the response of ecosystems to climate variability (Droughts) depend on structural variations and intactness?

E-3g: How do changes of nutrients (e.g. CO2 Fertilization) impact ecosystem(biomass change of intact forests) fluxes of carbon and water (ET)?

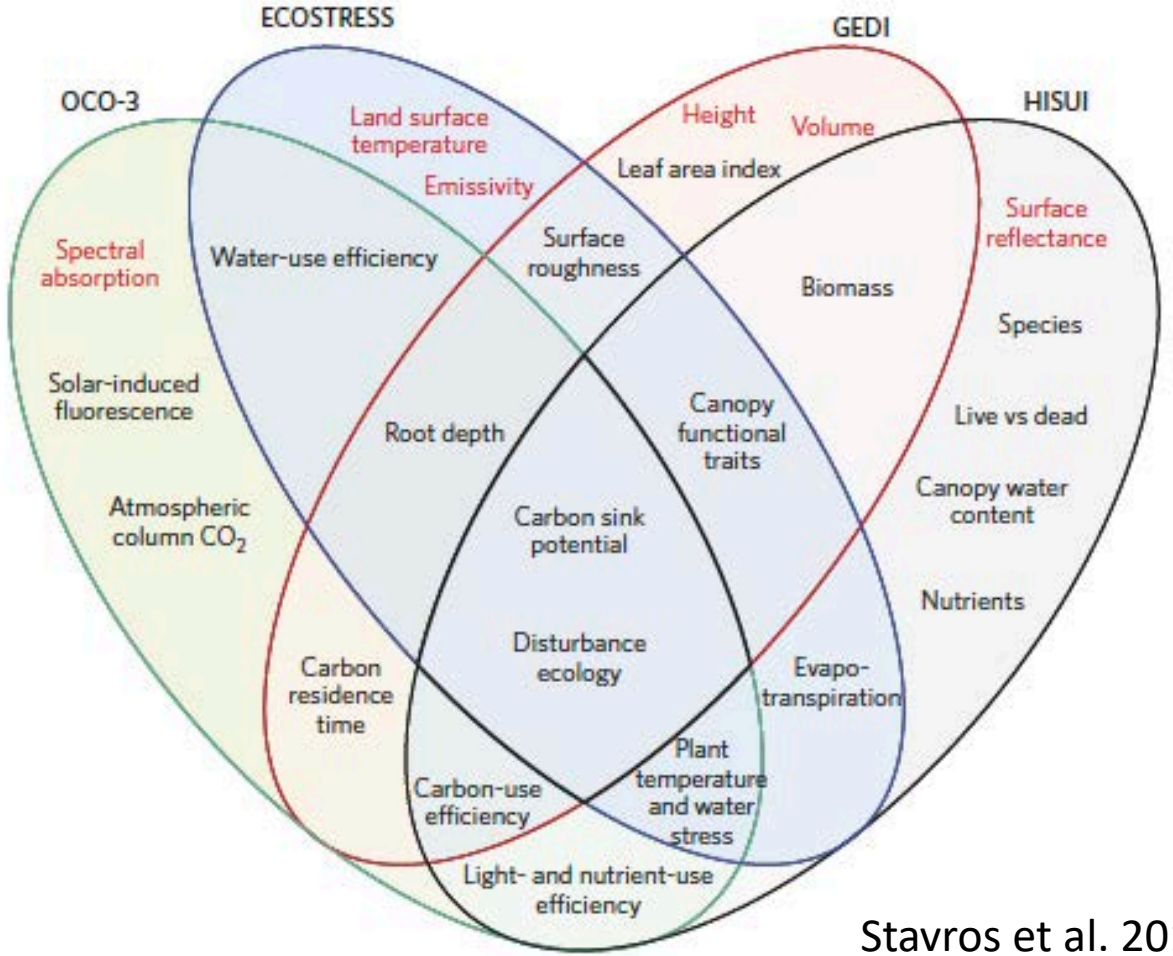
E-3h: How do light, water, and carbon use efficiency of global forests depend on the 3D structure (LAI profile, crown size, aerodynamic roughness, height) and dynamics?



Observations of Fluxes from Space



Schimel et al. 2019



Stavros et al. 2017

E-4 Carbon Accounting. How is carbon accounted for through carbon storage, turnover, and accumulated biomass? Have all of the major carbon sinks been quantified, and how are they changing in time?

E-4a: How does live vegetation biomass carbon distribution vary across landscapes?

E-4b: What are changes in C stock and net C fluxes due to fire, deforestation and reforestation and regrowth?

E-4c: What is the relative contribution of forest and nonforest woody vegetation to global carbon sinks and sources?

E-4d: How do spatial heterogeneity and dynamics of forest structure impact estimates of carbon stocks?

E-4e: How do the spatial extent and intensity of disturbance change vegetation carbon storage?

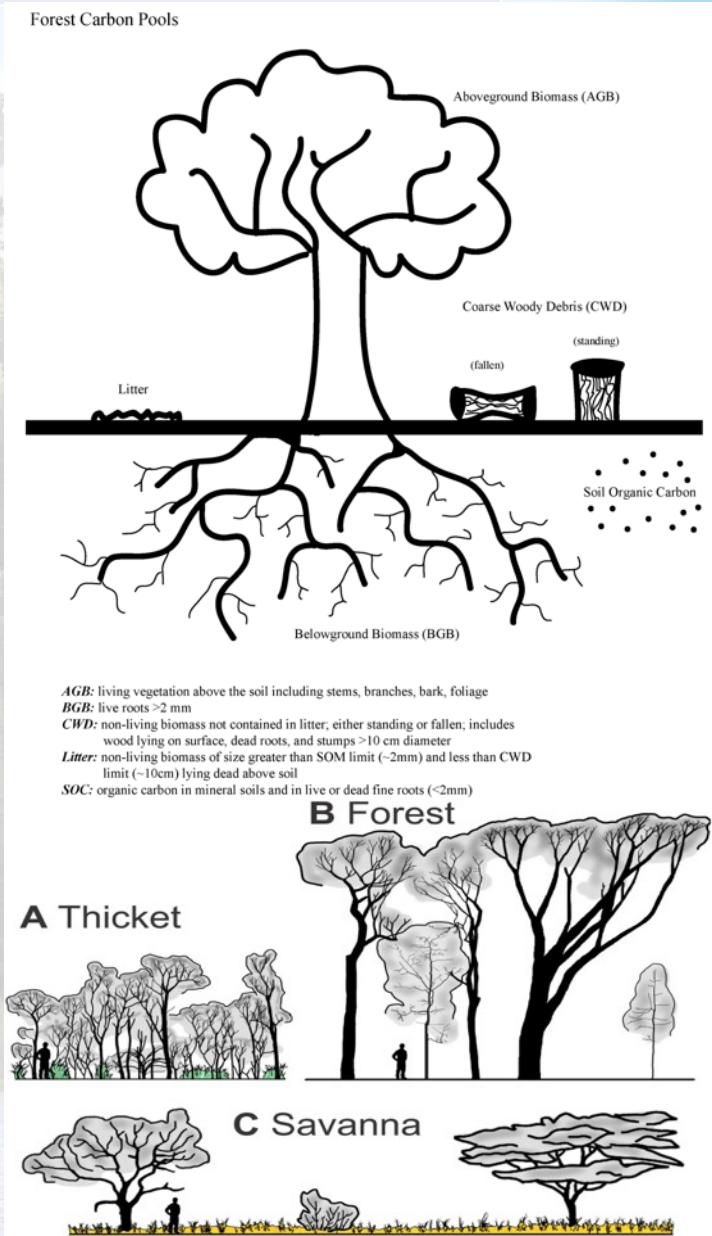
E-4f: What is the rate of carbon accumulation in regenerating vegetation?

E-4g: To what extent do old growth forests contribute to global carbon sink?

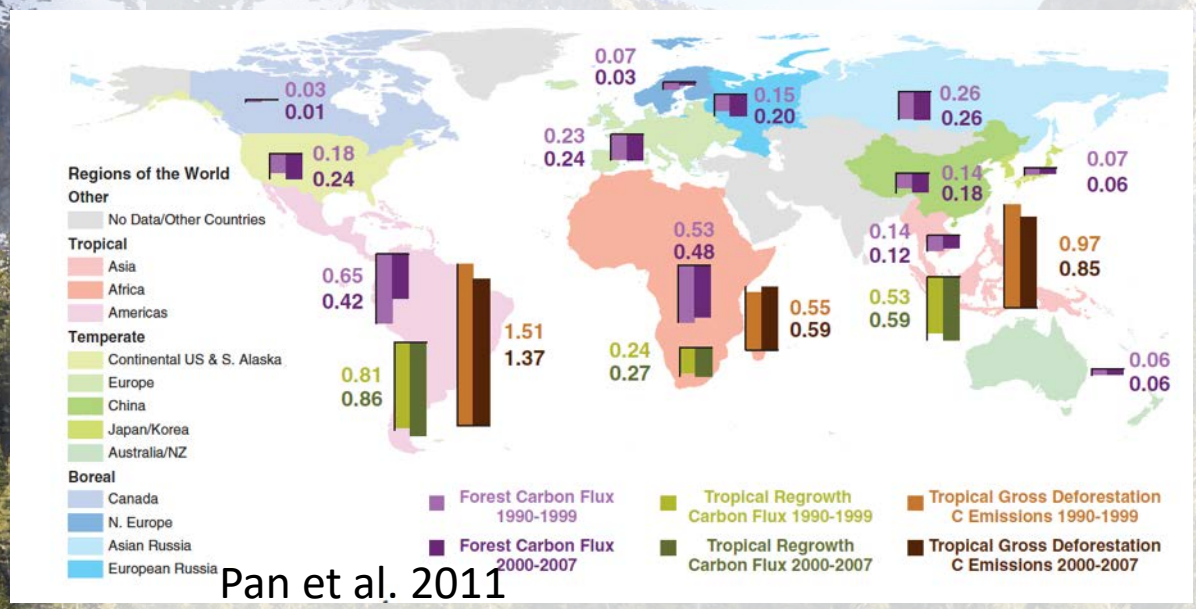
E-4h: What is the contribution of tropical degraded forests to annual carbon emissions and removals?

E-4i: How does carbon stored in other pools (below ground and dead wood) vary with above ground vegetation structure and dynamics?

E-4j: What is the relative contribution of background tree mortality and recruitments on forest carbon dynamics?

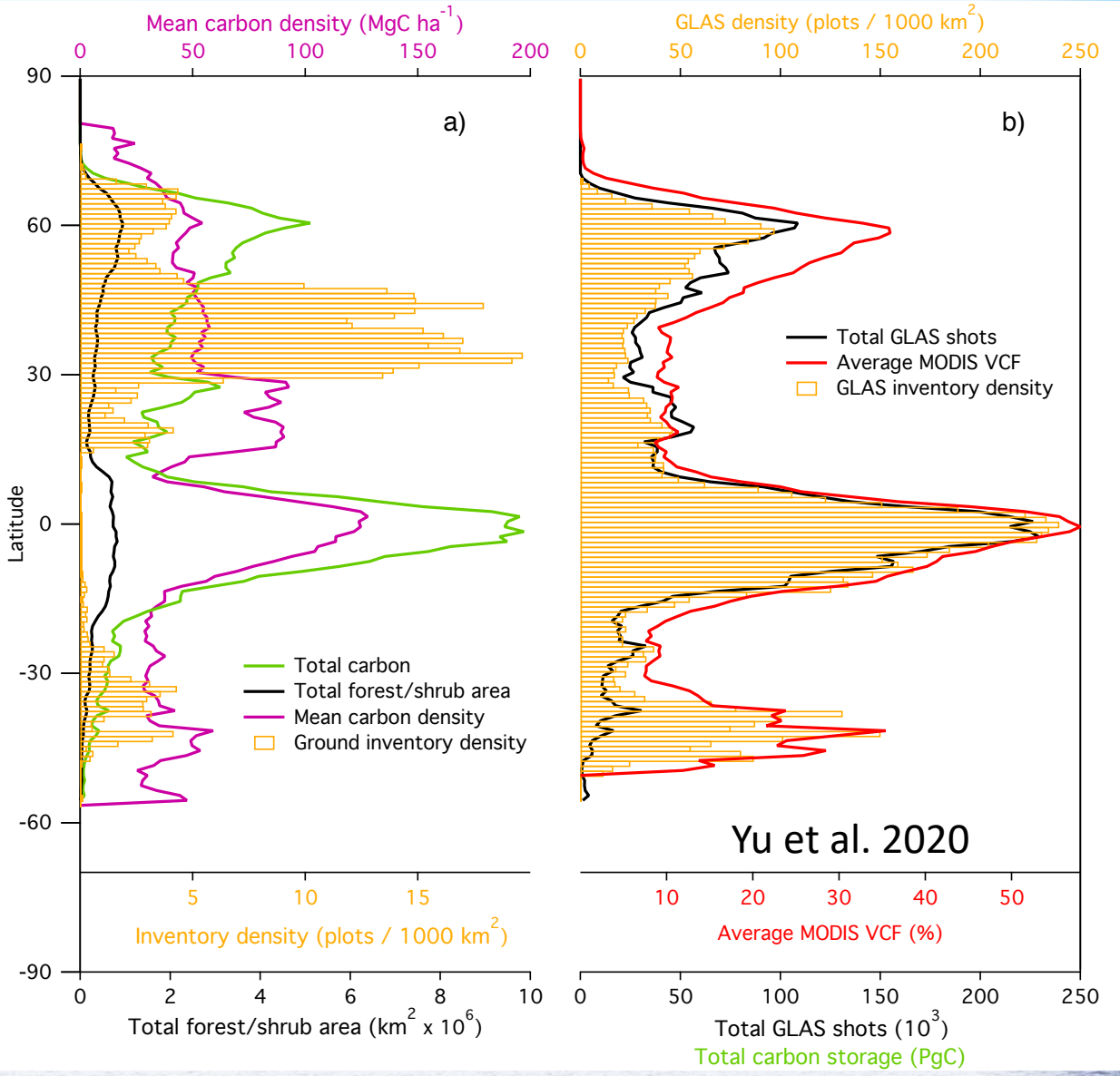


National Inventory Approach

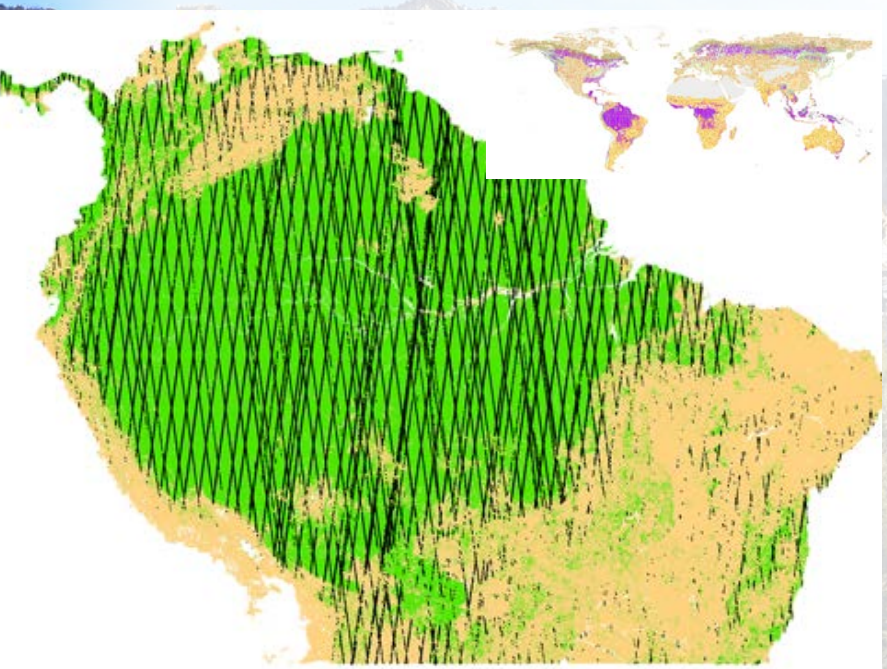


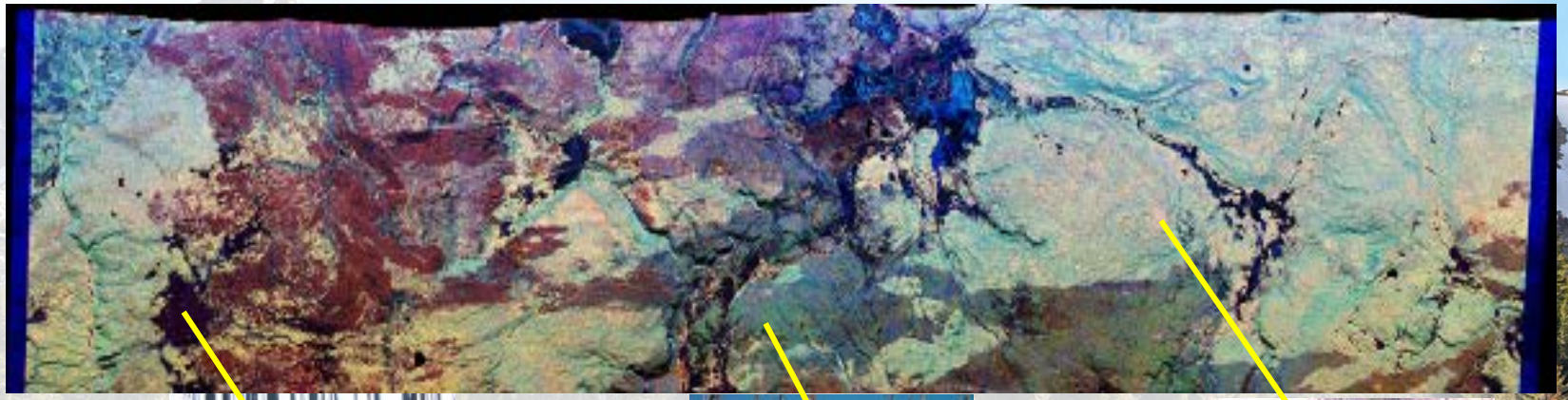
Pan et al. 2011

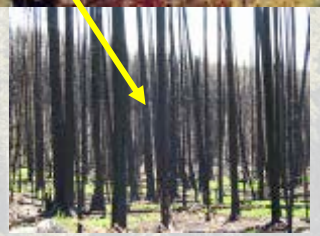
- Systematic National GHG Inventory for global vegetation does not exist
- Observations to harmonize vegetation inventory across spatial and temporal scales may the critical contribution of remote sensing techniques from space.



Vegetation Inventory from Space



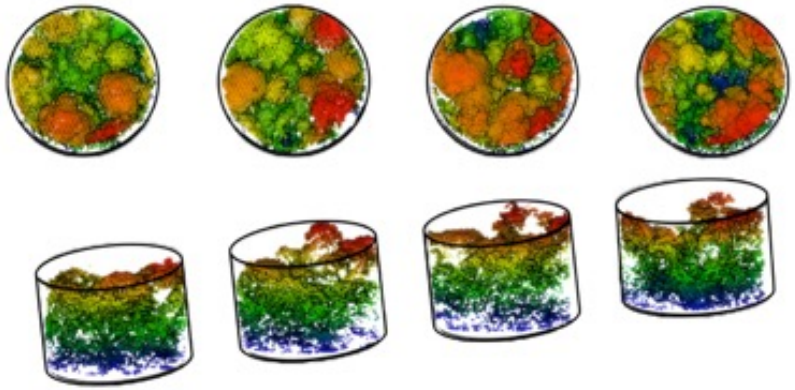




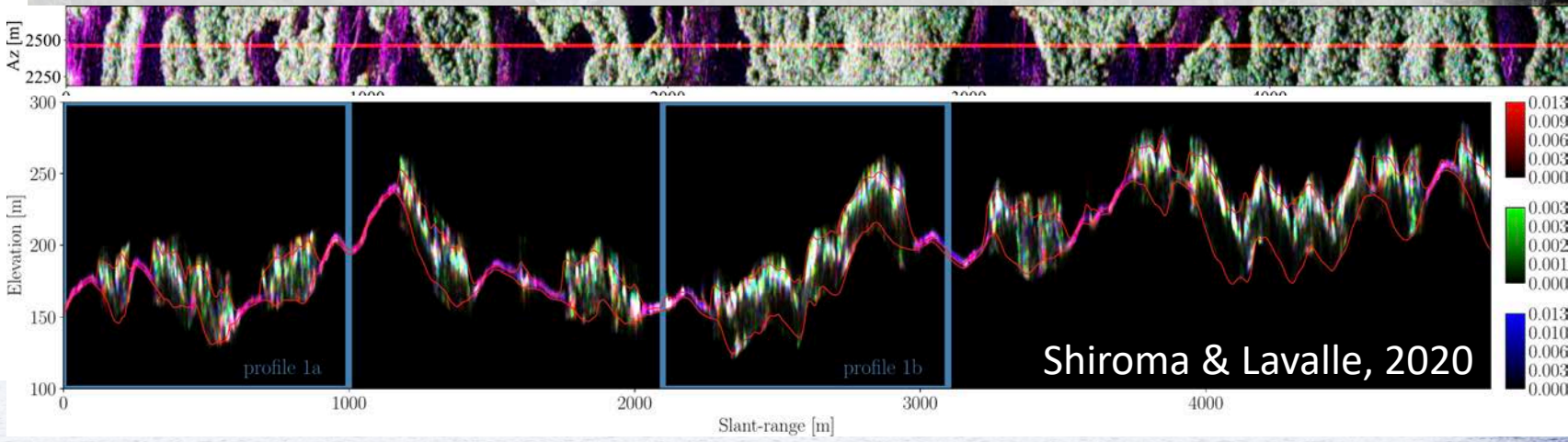
Burned

Regrowth

Pine beetle Mortality



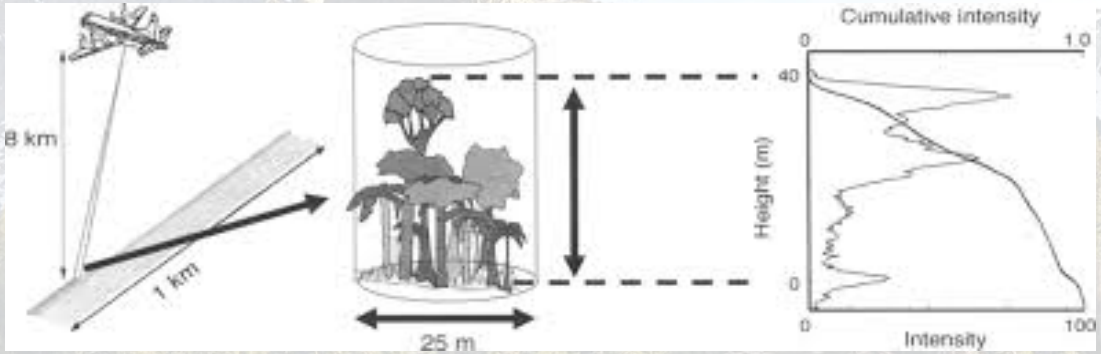
Saatchi et al. 2015

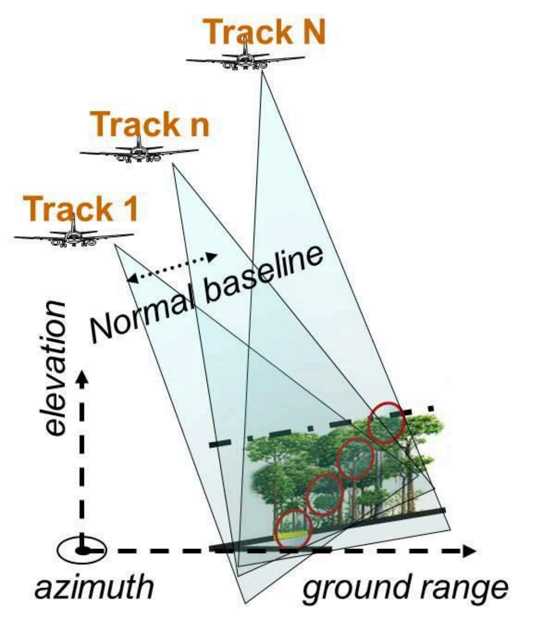


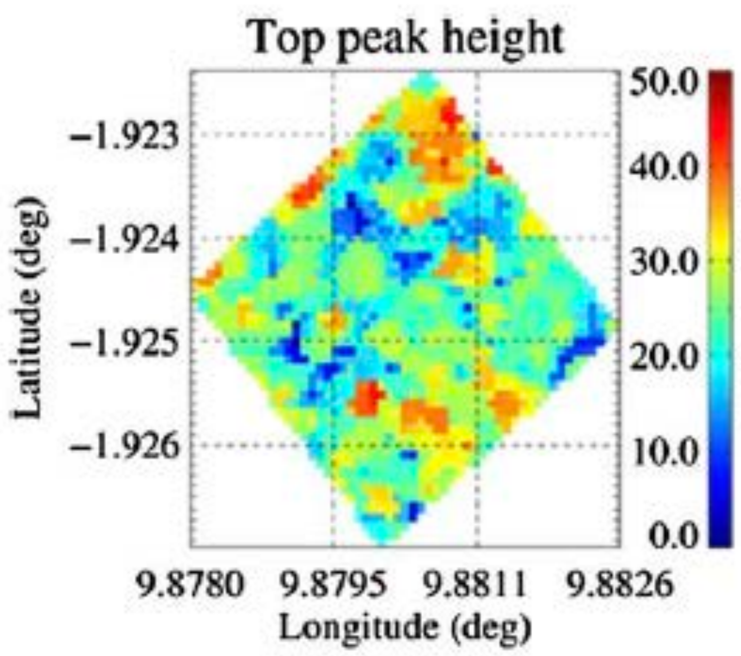
Shiroma & Lavalle, 2020

Synergistic Observations of 3D Structure

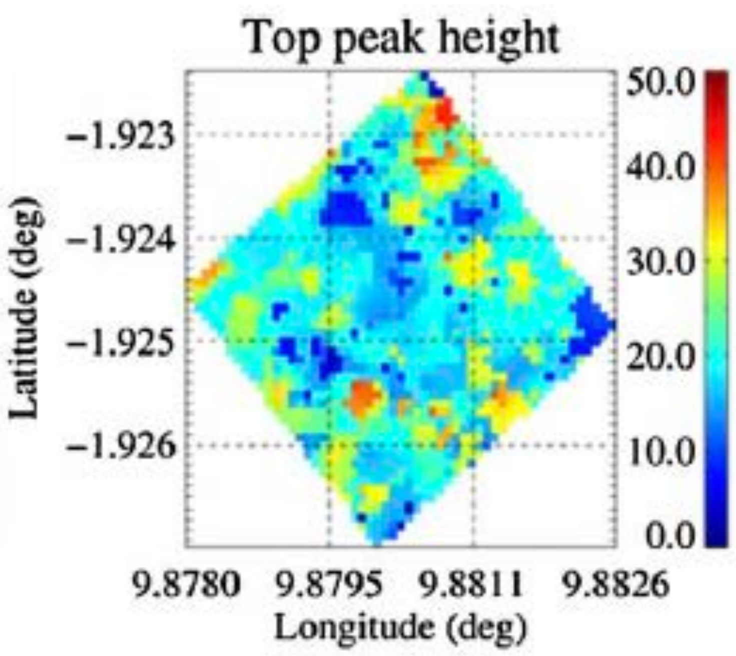
Pardini et al. 2018



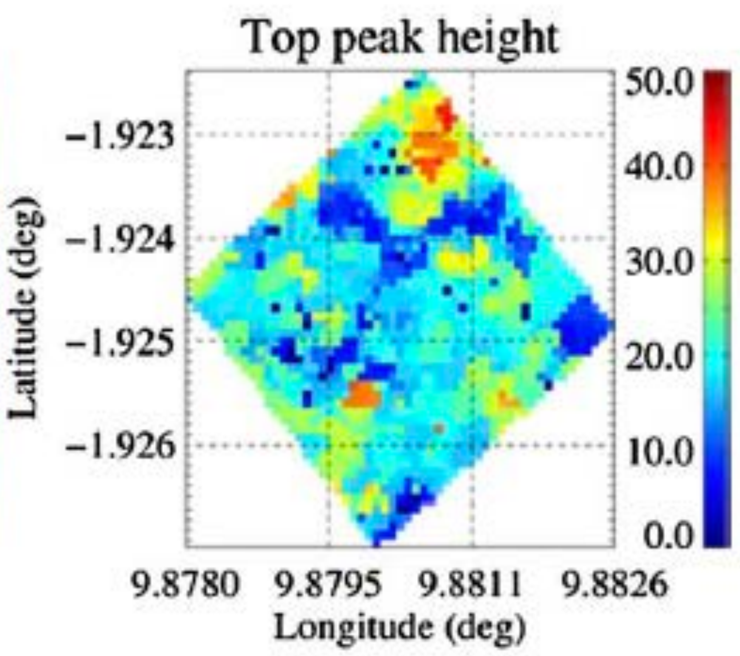




LVIS Waveforms



L-band TomoSAR Waveforms



P-band TomoSAR Waveforms

E-5 Carbon sinks: Are carbon sinks stable, are they changing, and why?

E-5a: What is the annual estimates of terrestrial carbon sinks in live vegetation?

E-5b: What is the rate of post-disturbance carbon recovery of vegetation?

E-5c: How does climate impact carbon sink stability across local to regional scales?

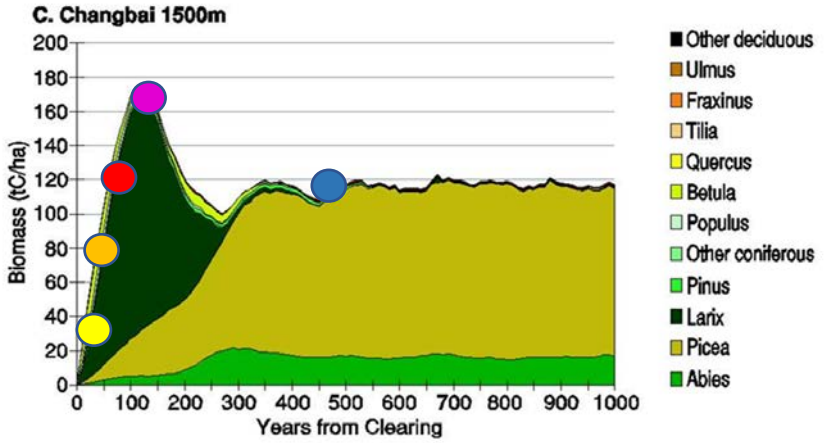
E-5d: How does ecosystem resilience change to cascading effects of disturbance and changes of structure?

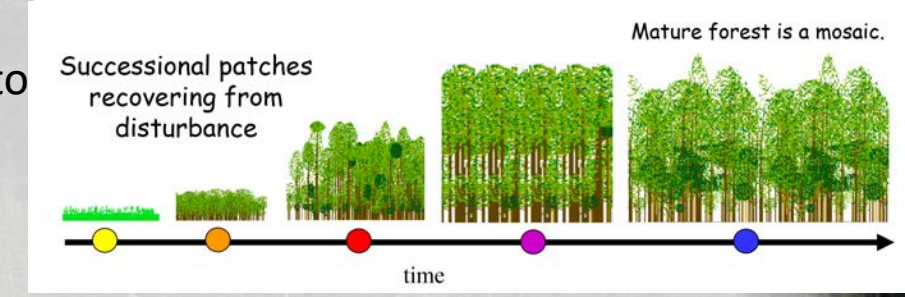
E-5e: How do disturbance and recovery processes change global carbon sinks?

E-5f: How does forest structure and diversity impact response of the ecosystems to disturbance?

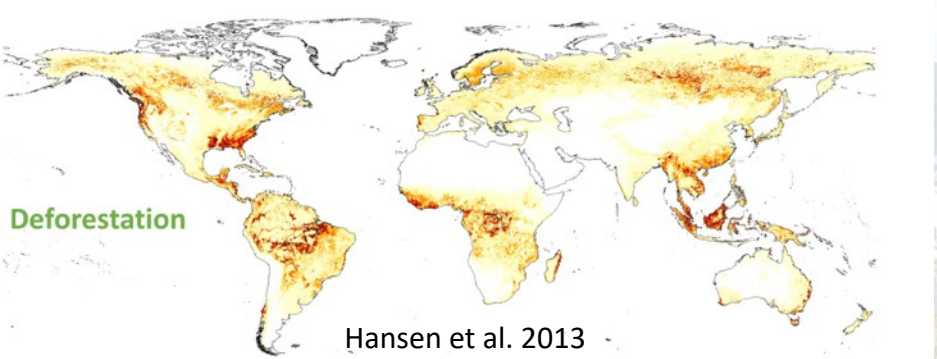
E-5g: What is the response of vegetation productivity to variability and extreme climates

E-5h: To what extent afforestation improve and sustain carbon sinks in vegetation?

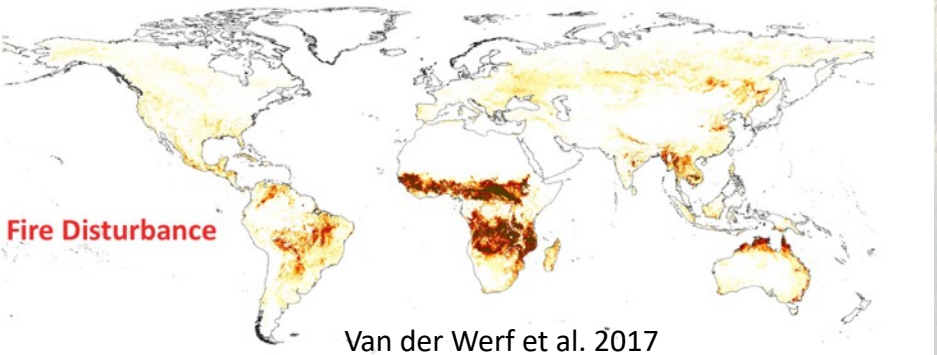




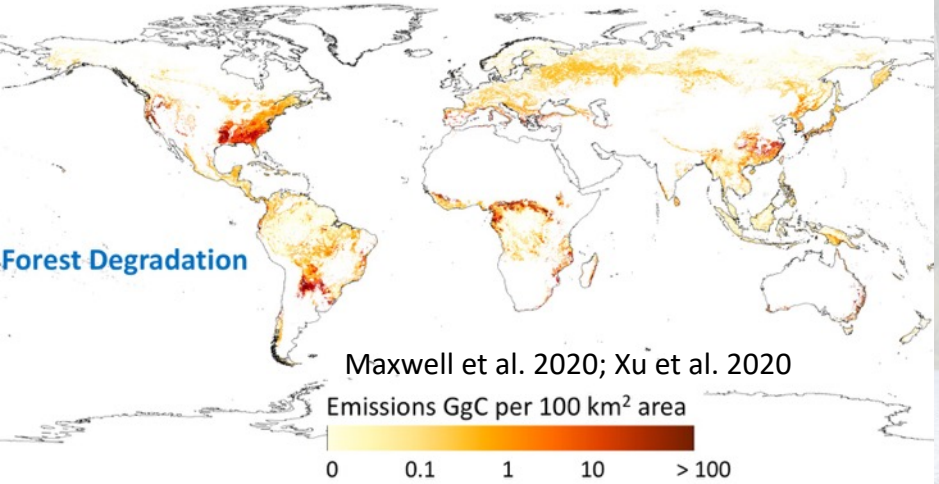
Landscape Scale Carbon Stocks and Changes



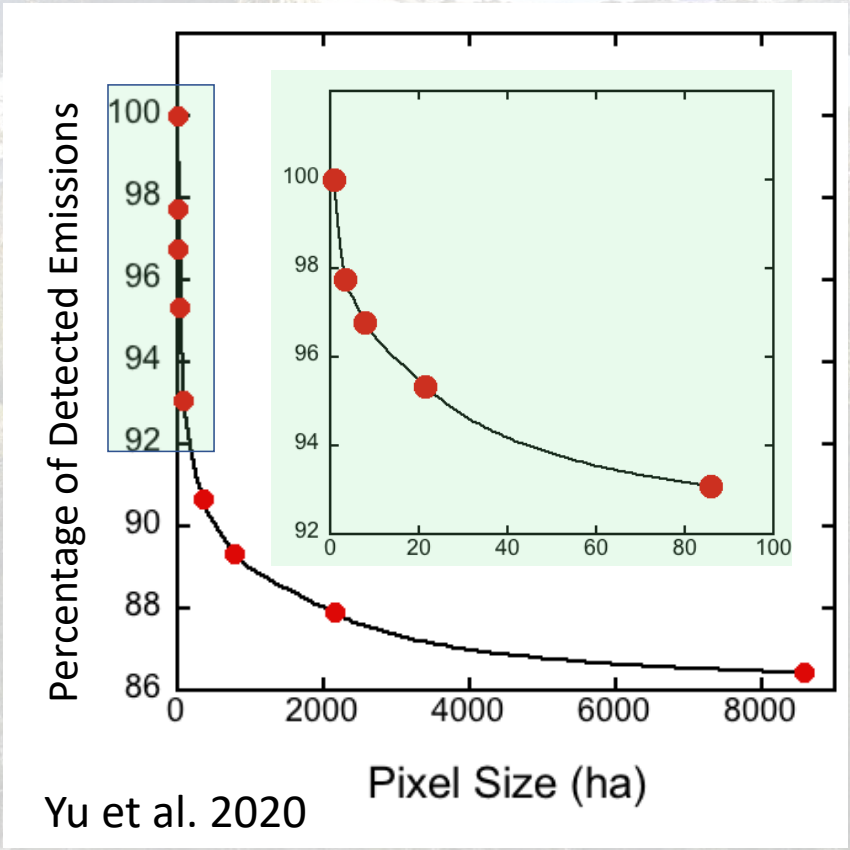
Hansen et al. 2013



Van der Werf et al. 2017



Maxwell et al. 2020; Xu et al. 2020



Yu et al. 2020

More than 90% of forest disturbance occurs at scales of ≥ 1-ha

Carbon stocks in vegetation have large heterogeneity at landscape scales due to edaphic and disturbance gradients

Uncertainty in estimates of emissions and removals of carbon are reduced significantly the scale of ≤ 1-ha.

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

Data Product Requirements

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)

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 - example

Science and Applications				Level 3 or 4 Product					Provide thre
Goals	Objectives	Targeted Observable(s)	Physical Parameter(s) Required		Area of Interest	Coverage (%)	Smallest Feature Resolution (m)		Sampling Distanc (m)
							Horizontal	Vertical	
						types. Numbers of 10-30% annually			
carbon emission and removals from anthropogenic and natural disturbance and recovery processes	How does changes of aboveground vegetation live biomass contribute to global gross carbon sources and sinks?	Changes of vegetation 3D structure	Height change, gap dynamics, tree cover change	biomass loss and gain, tree mortality, vegetation productivity rate	Global including trees and shrublands	100%	minimum spatial correlation length of tree distribution (~0.1-1-ha), typically 3 x crown size in tropical forests, and approximately the spatial scale biomass becomes normally distributed across the landscape (> 100 m for tropical forests, and 20-30 m in	separating change of height of less 1 m in forests, and less 0.5 m in shrublands. The requirement requires averaging over the horizontal scales of 0.1-1.0 ha.	10-30 m horizontal, < 1 m vertical, (note: sampling distance may be controle the spatial scale of disturbance. From Lands time series analysis (Han al. 2013), it is shown that than 90% of global fores disturbance occurs at sca > 1-ha. only 10% are be ha and a much smaller s below 0.1 ha (30 m resol

Forest Resources & Agroforestry Applications & Deforestation

Jon Ranson, Robert Treuhaft

Forest Resources & Agroforestry Applications & Deforestation

E-7 **What is the composition and status of natural and agroforest systems, and how are they changing under the influence of human activities and natural events?**

E-7a What are the growth and removal rates of forests*?*

E-7b What is the areal coverage and change of commercial forests?

E-7c How and why are forest heights changing?

E-7d How does land use history impact tree density and growth rate?

E-7e How does forest health and productivity relate to vegetation structure and topography, and how can better estimates of GPP be made based on that information?

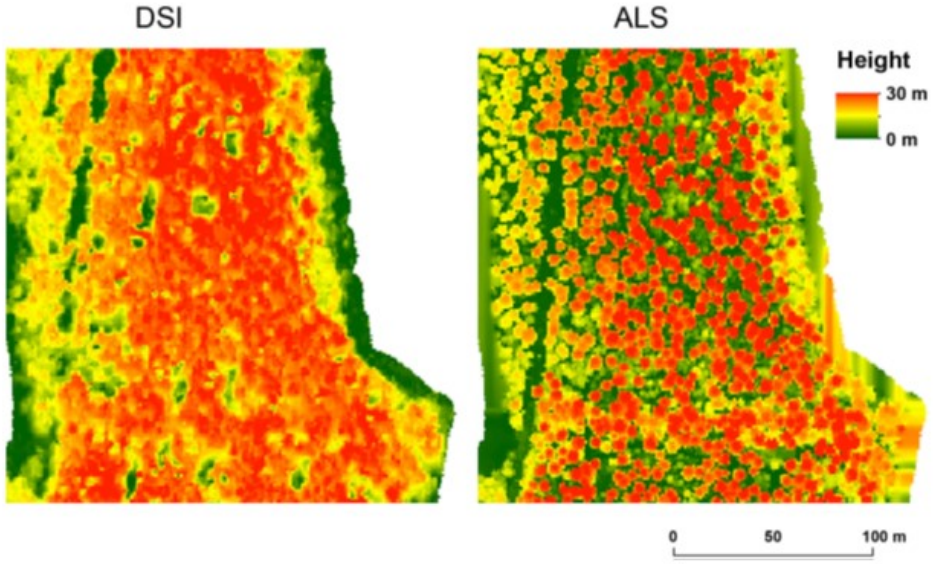
E-7f What are the connections of forest structure and functional diversity and biodiversity?

E-7g How does stem density vary with edaphic and climate factors?

E-7h How has a natural disaster (e.g., fire, flood, windthrow) affected the forest?

E-7i How is vegetation structure within protected areas and surrounding areas changing?

Airborne laser scanning and digital stereo imagery measures of forest structure: Comparative results and implications to forest mapping and inventory update



DSI – similar outer canopy height metrics as ALS, needs a DEM to get canopy height model.
ALS – better canopy penetration for canopy interior and understory.

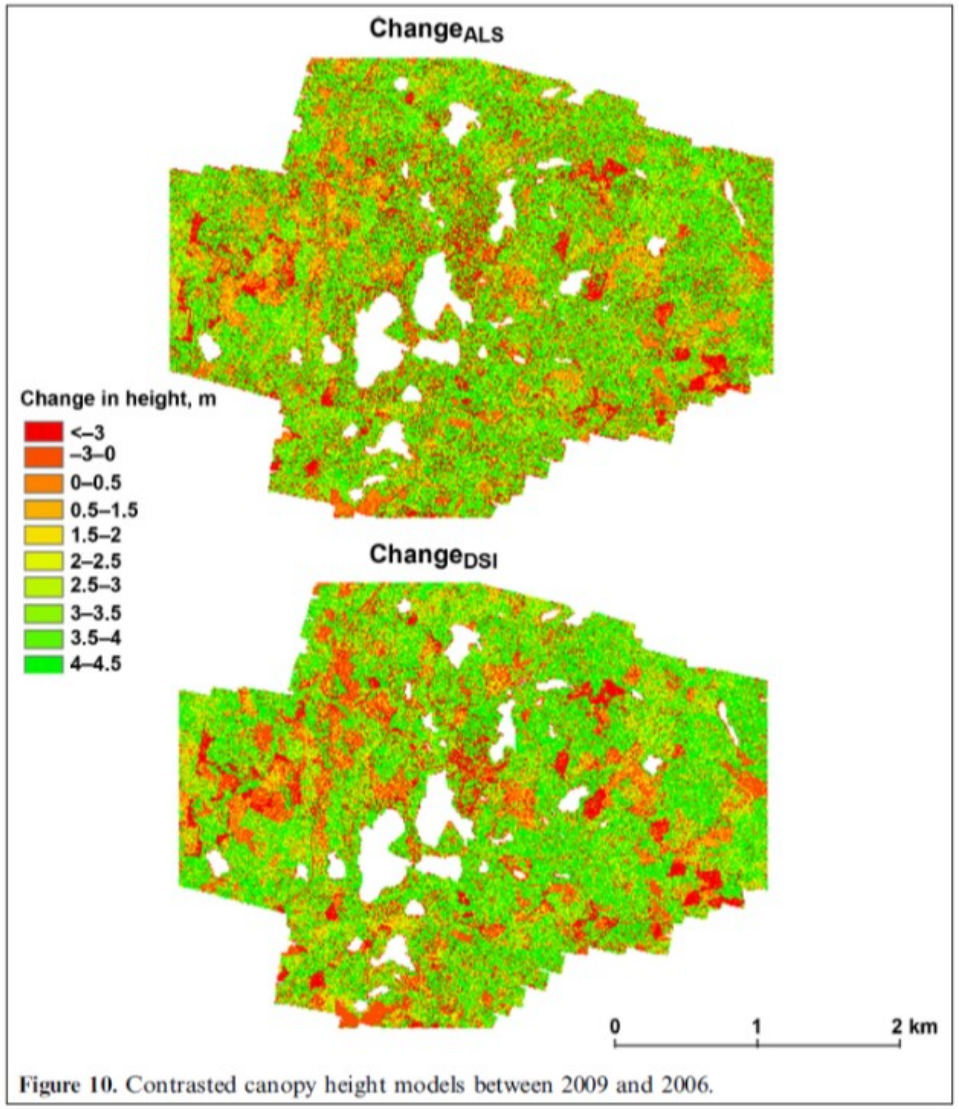
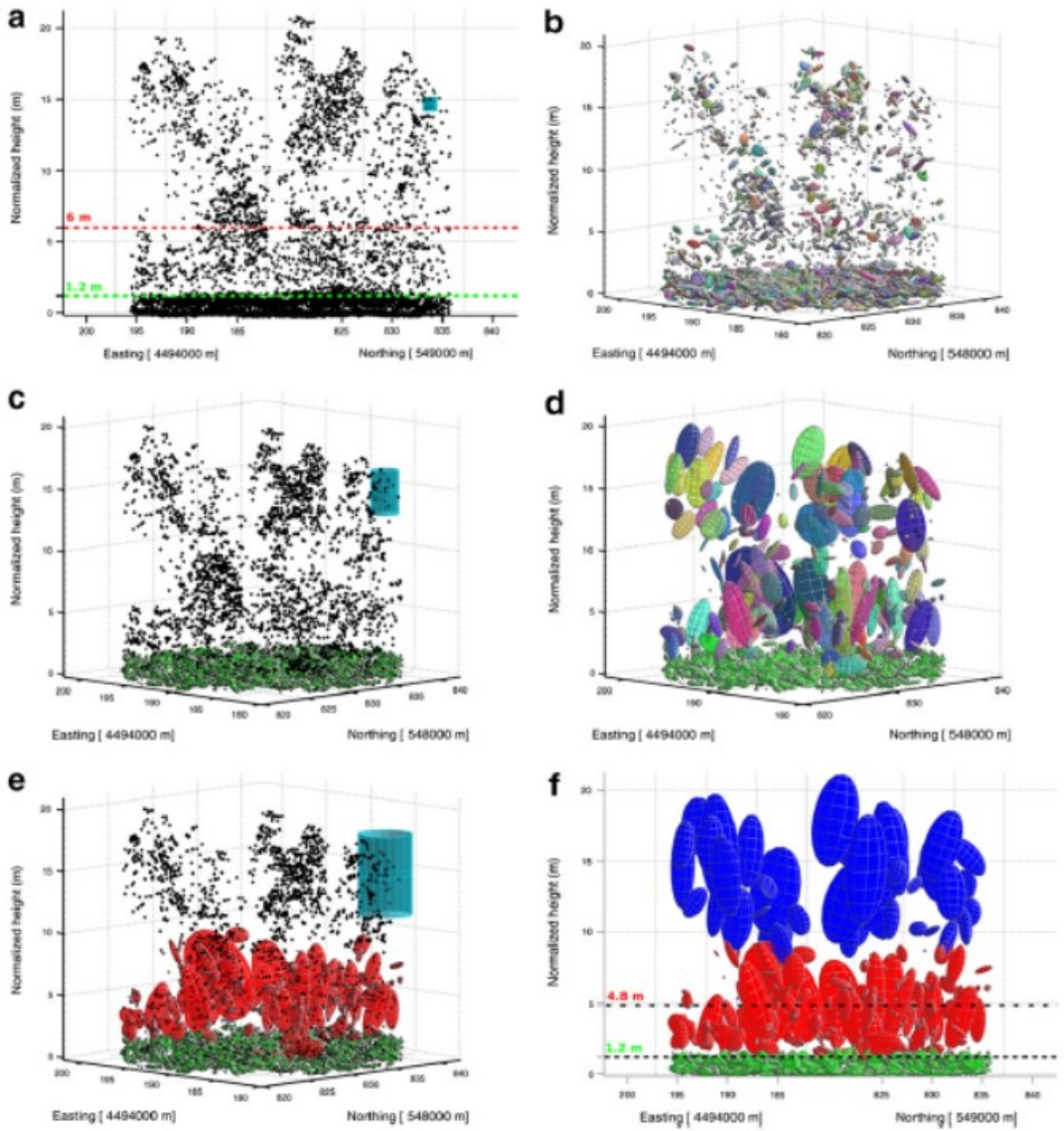


Figure 10. Contrasted canopy height models between 2009 and 2006.

Vastaranta et al. 2013

3-D mapping of a multi-layered Mediterranean forest using ALS data



Ferraz et al. 2012

Agroforestry Applications

How do we monitor agroforestry systems to effectively manage forest products and ecosystems services?

E-7j How do we monitor tree cover in agricultural landscapes in order to safeguard their economic benefits and ecosystem services by providing timber, non-timber products and food?

E-7k Are agroforestry initiatives achieving their objectives to increase tree cover and local ecosystem services within agricultural landscapes?

E-7l Which areas are logged and when were they logged?

E-7m Where is conversion of primary forests to silvicultural production areas occurring? (e.g., Palm Oil).

E-7n How are agroforestry systems distinguished from natural forest systems?

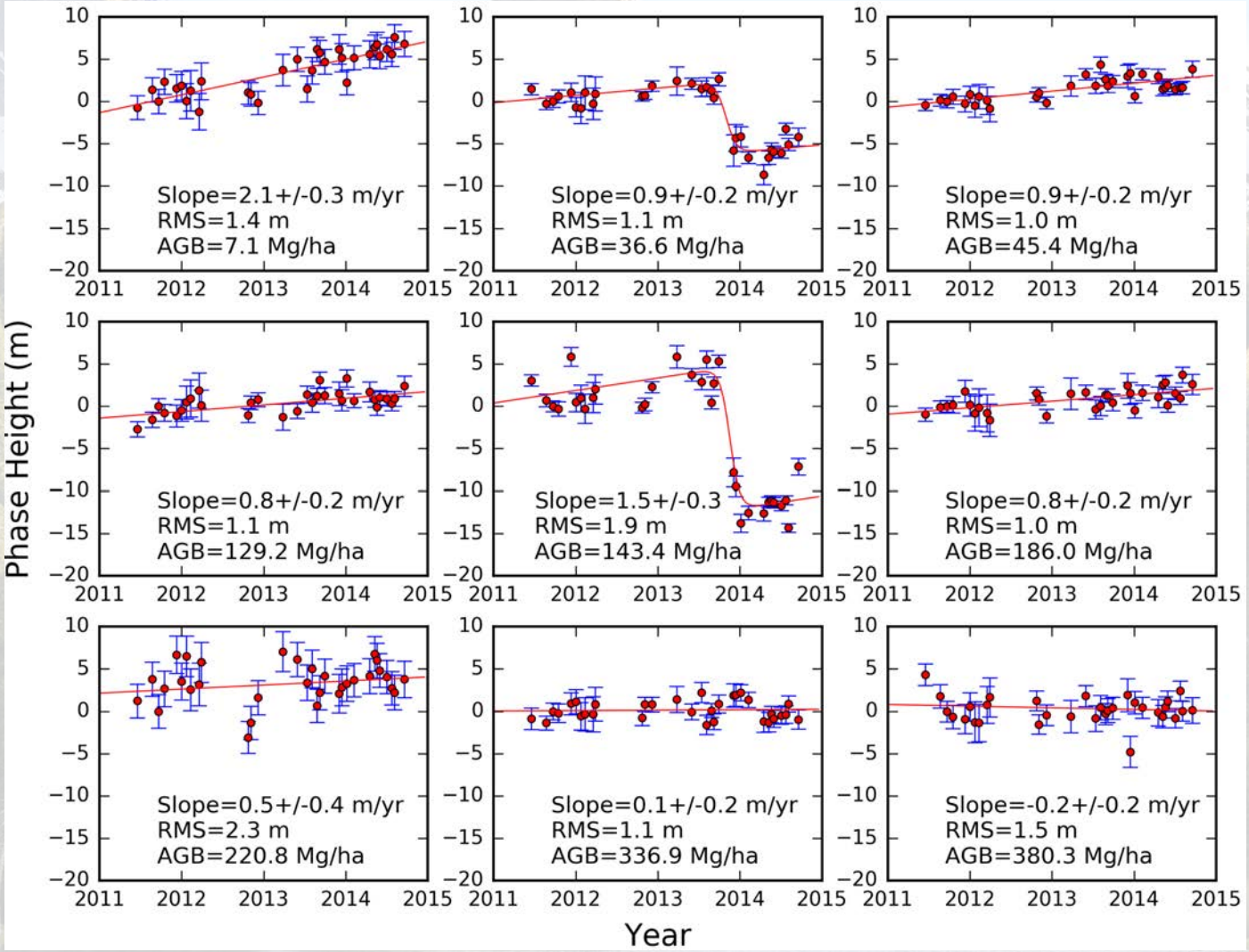
Deforestation Monitoring

E7 **Forestry Ecosystems & Agroforest Applications & Deforestation. What is the composition and status of natural and agroforest systems, and how are they changing under the influence of human activities and natural events?**

E7-o Support acquisition of REDD+ (reduce emissions from deforestation and forest degradation) activity data by (1) providing spatially explicit forest transition matrix (Forest to degraded to non-forest).

E7-p Routinely perform detailed detection of small spatio-temporal-scale changes in forest carbon stock, with minimal latency, under the United Nation's effort REDD+.

The Spatio-Temporal Scale of Deforestation



- InSAR/TanDEM-X phase height versus time for 9 plots, including 2 agriculturally cleared tropical forests in Brazil

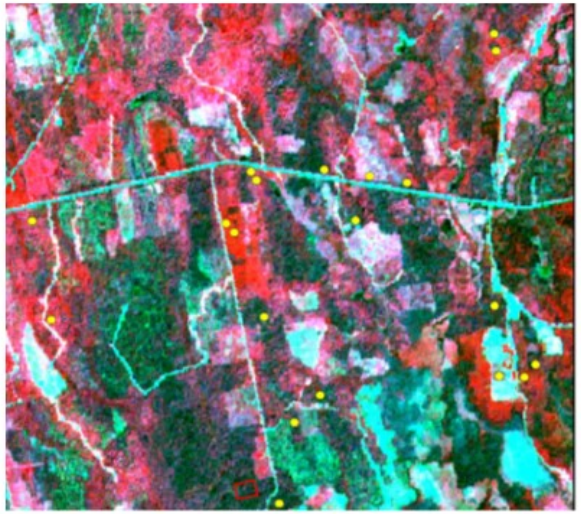
Treuhaft et al. 2017

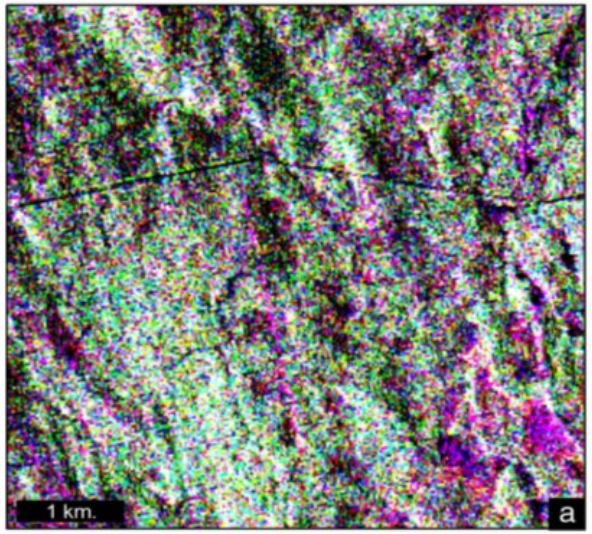
Back Up

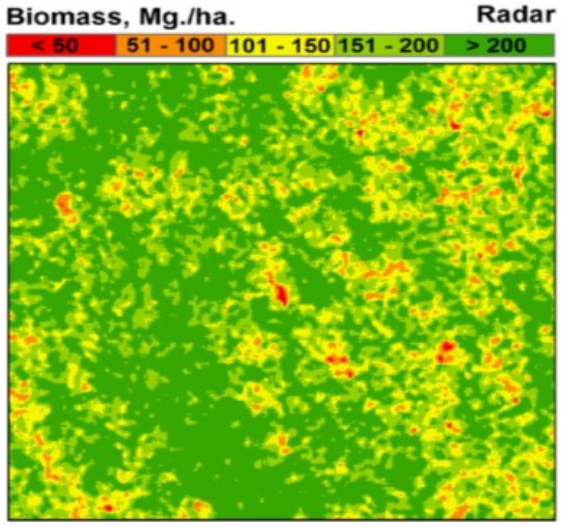
Forest mapping from lidar and radar synergies

PALSAR

ASTER

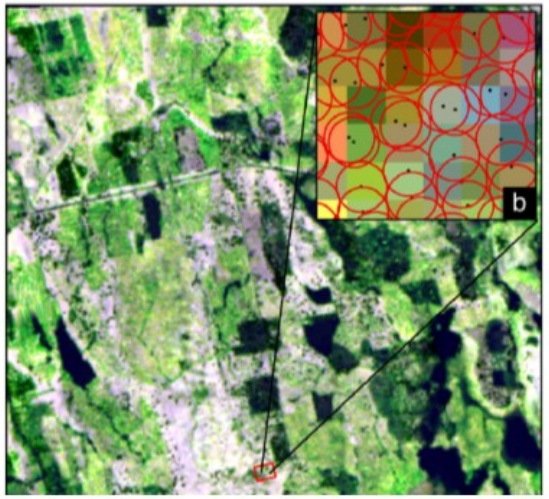


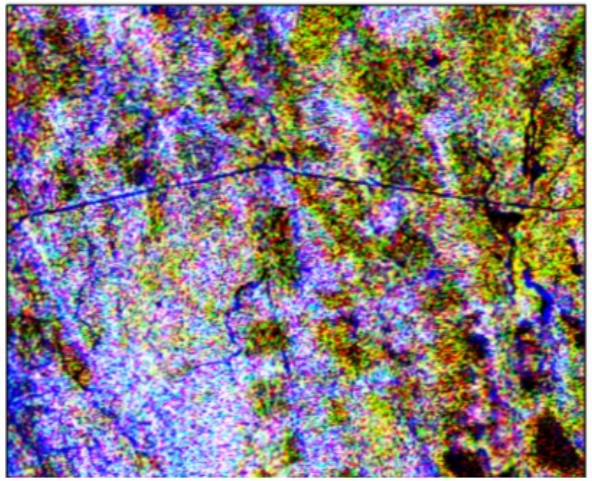




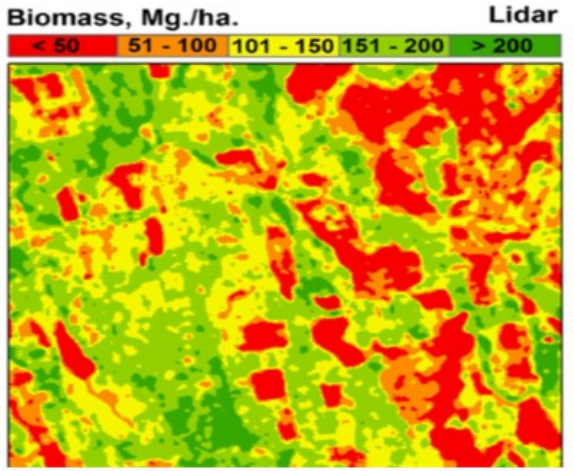
PALSAR +SRTM

LVIS





SRTM DSM



LVIS

Sun et al. 2011

Fire, Agriculture & Wetland Applications

Cathleen Jones

JPL

Goals & Objectives: Wildfire Applications

E-8 **How does vegetation structure relate to fire risk, and how does fire and fire regime impact regeneration and biomass in different biomes?**

E-8a How does sub-canopy structure (<10m), as a function of fuel type and condition, map into fire danger and spread?

E-8b What is the the impact of fire regime on forest biomass and vertical structure?

E-8c Is fire regime changing and if so, how (regional scale)?

E-8d What is the status of a forest in terms of fuel load, type and condition during high fire risk conditions and pre-to-post fire (rapid assessment)?

E-8e Post-fire, what is the depth of fire debris material?

Targeted Observable: Vegetation Structure, Topography

Derived Parameters, e.g., Vegetation Height, Vegetation Cover, 3D Vegetation Structure, Biomass, Bare Earth Topography, Highest Surface Elevation

Ancillary Information

Goals & Objectives: Agriculture Applications

E-9 **How does crop health and productivity relate to vegetation structure and topography, and how can better estimates of current and forecasted yield and risk be made based on that information?**

E-9a What is the crop yield/biomass (field level)?

E-9b What is the crop growth stage/phenology as a function of time during the crop season? (NOTE: needed monthly)

E-9c What is the current and forecasted risk of crop loss, e.g., from disease/drought?

E-9d Where is cultivation taking place on steep slopes?

E-9e How is crop productivity related to topographic position?

E-9f How is crop yield/biomass changing (regional level)?

Targeted Observable: Vegetation Structure (Forest & Non-Forest), Topography

Derived Parameters , e.g., Vegetation Height, Vegetation Cover, 3D Vegetation Structure, Biomass, Bare Earth Topography, Soil Moisture

Ancillary Information

Goals & Objectives: Wetland Management

E-10 **What are the location and extent of wetlands of different types (e.g., fresh or salt water marsh, mangrove, wooded wetlands), and how are they changing??**

E-10a What is the location and extent of forested wetlands, and how is this changing over time (local scale)?

E-10b What is the location and extent of marshlands , and how is this changing over time (local scale)?

E-10c How are forested wetlands changing, either naturally or under human influence (regional-to-global scale)?

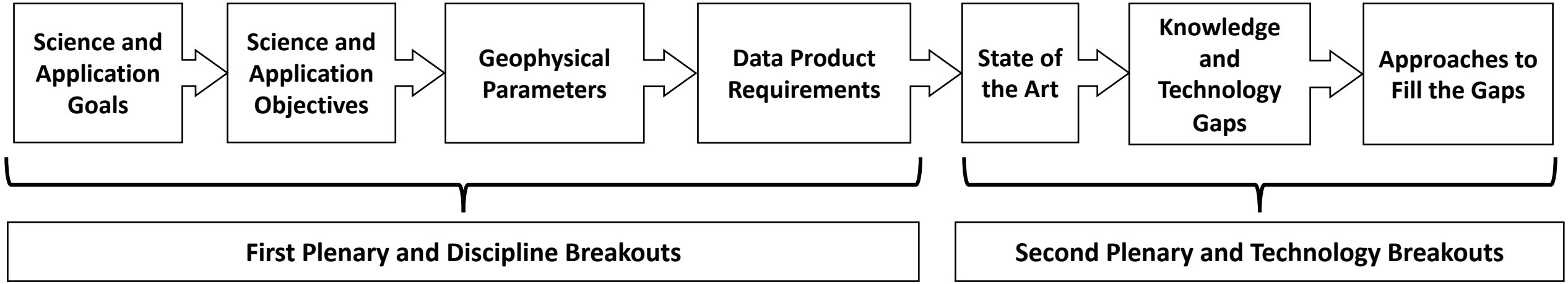
E-10d How are marshlands changing, either naturally or under human influence (regional-to-global scale)?

Targeted Observable: Vegetation Structure (Forest & Non-Forest), Topography, Bathymetry

Derived Parameters , e.g., Vegetation Height, Vegetation Cover, 3D Vegetation Structure, Water Surface Elevation, Bare Earth Topography, Bathymetry (water bottom topography)

Ancillary Information

Science and Applications Traceability Matrix (SATM)



- Science and applications goals and objectives both contribute to the STV SATM

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

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)

Temporal

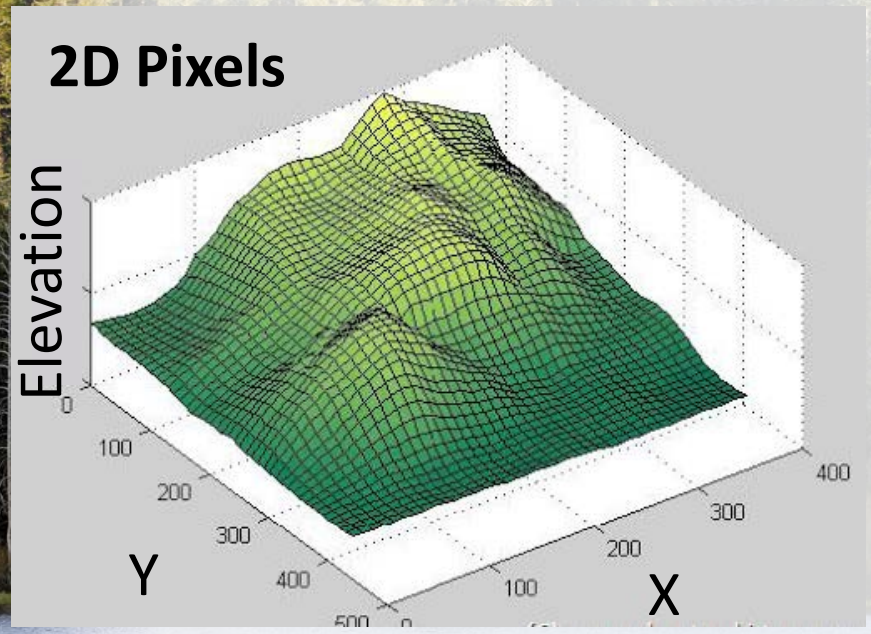
Level 3 or 4 Temporal Requirements Provide three requirements: (1) from the Decadal Survey (NA if not specified), (2) aspirational and (3) threshold					
Rate of Change Accuracy (parameter/yr)	Size of Area Observed to Determine the Rate of Change (sq km)	Latency (days)	Repeat Frequency (days)	Repeat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

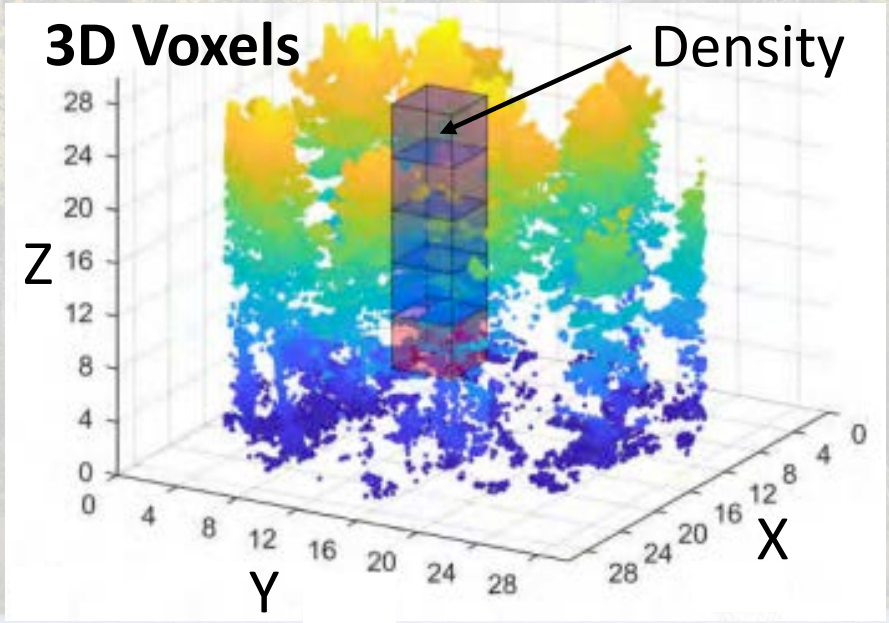
State of the Art → **Knowledge and Technology Gaps** → **Approaches to Fill the Gaps**

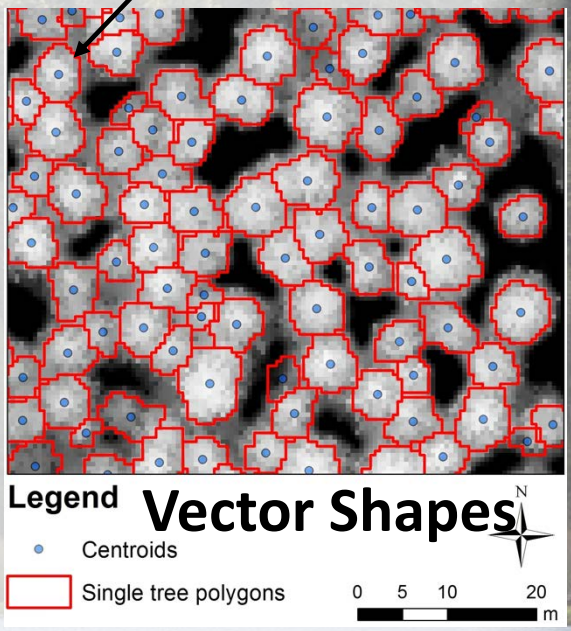
Current Technology Solutions		Identified Gaps		Potential Activities to Close Gaps				
Applicable Sensor Type(s)	Are requirements currently met? Y/N	Scientific Knowledge	Technology Capabilities	Simulations	Experiments	Existing Data Analysis	Instrument Development	Platform Development

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)





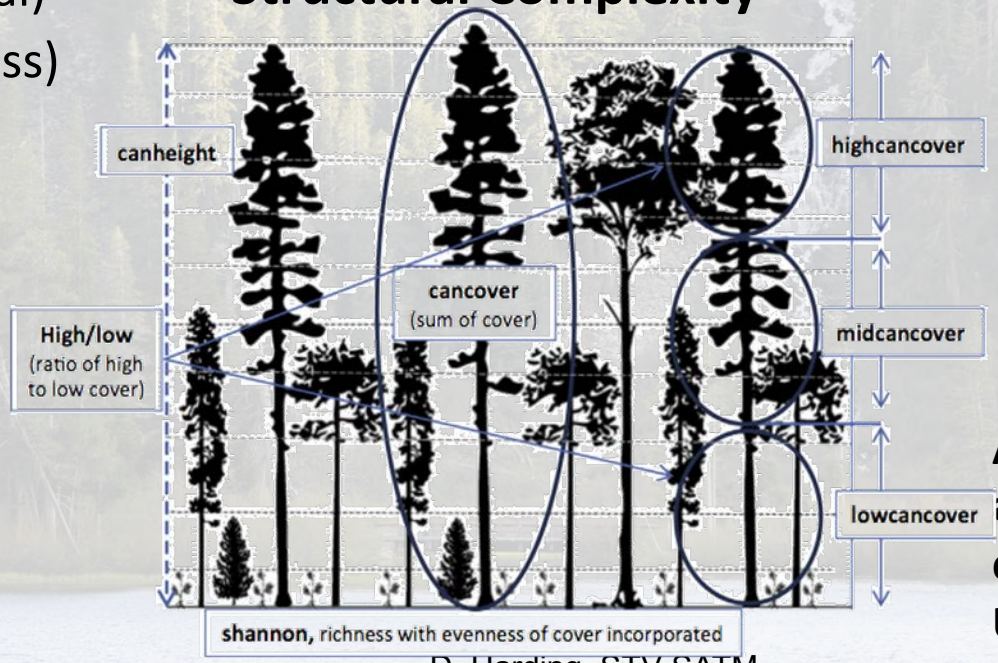


Candidate 2D Products

- **Gridded pixel representation of a geophysical parameter**
  - **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
Vertical Plant Area profile

Structural Complexity



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

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

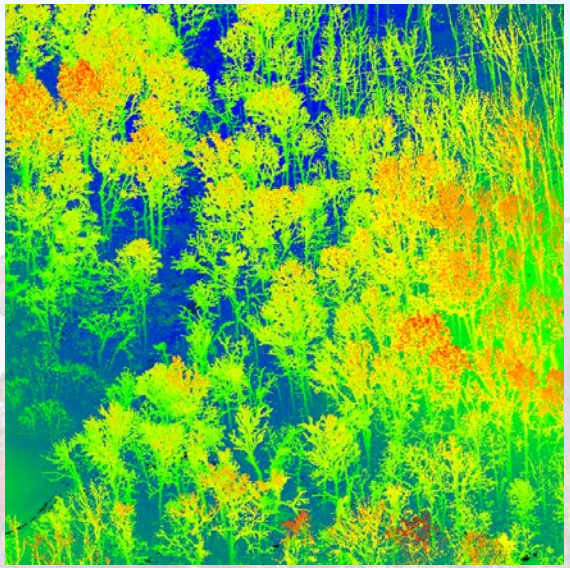
Candidate Vector Products

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

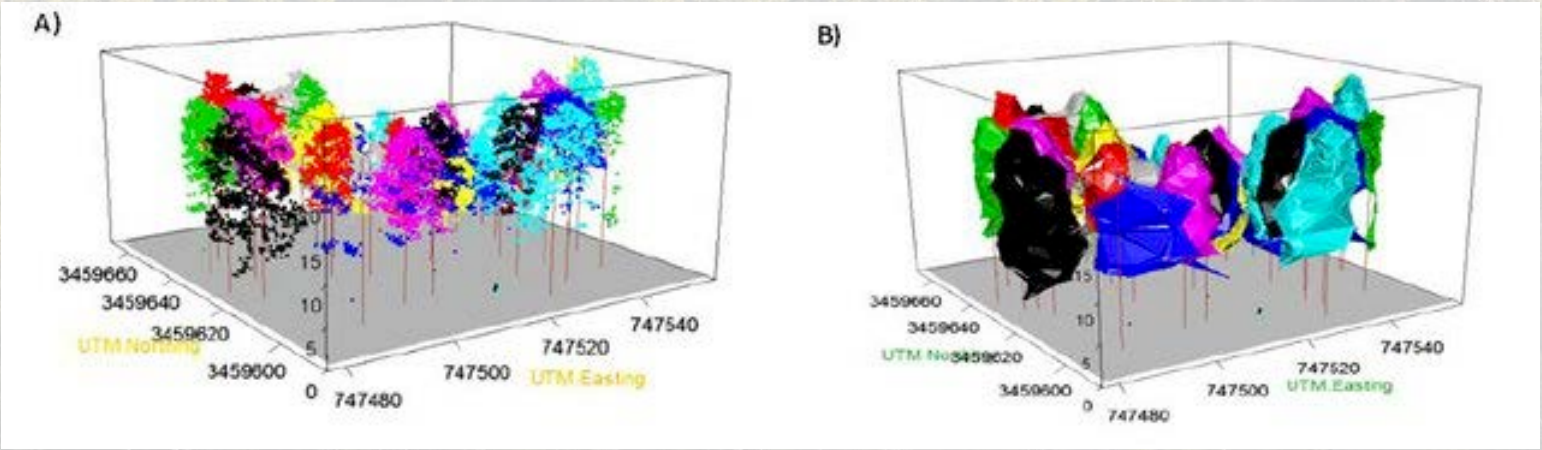
    Tree or shrub crowns

    Stems

    3D Shapes, objects



GMU Drone LiDAR. ForestGEO Front Royal



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 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)?

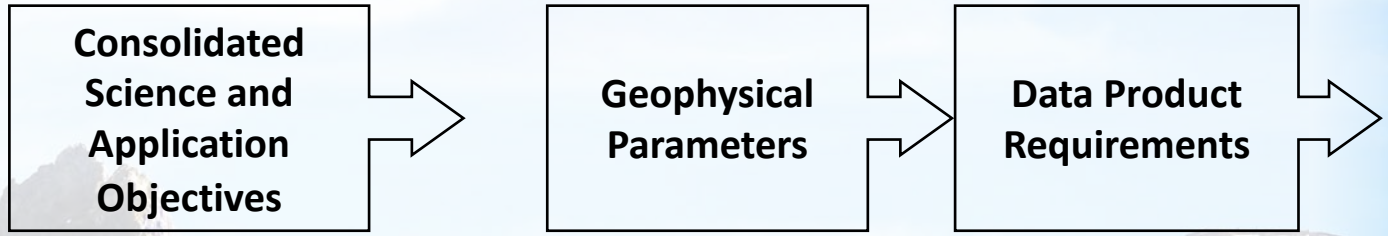
- **Rate of Change Accuracy (when applicable to an objective)**

  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.

SATM - example



- Question / objective: How is climate change effecting the structure of boreal forests?
- Geophysical Parameters (Veg structure): Vegetation height, Canopy cover fraction (CCF), 3D structure (e.g. CCF profile), above ground biomass, tree crowns,
- Each Parameter needs a L3 or L4 product assigned to it, with data product requirements / properties (spatial and temporal, accuracy)

SATM - example

Consolidated Science and Application Objectives → **Geophysical Parameters** → **Data Product Requirements**

Science and Applications			Level 3 or 4 Product	Level 3 or 4 Spatial Requirements Provide three requirements: from the Decadal Survey, if specififed, aspirational and threshold		
Objectives	Targeted Observable(s)	Physical Parameter(s) Required		Provide three requir		
			Coverage (%)	Smallest Feature Resolution (m)		Sampling Distance (m)
				Horizontal	Vertical	
How is climate change effecting the structure of boreal forests?	Vegetation Structure	Vegetation Height	100% 30%	10m tree stand 20m tree stand	NA	3m 7m

SATM - example

Consolidated Science and Application Objectives → **Geophysical Parameters** → **Data Product Requirements**

Science and Applications			Level 3 or 4 Temporal Requirements Provide three requirements: from the Decadal Survey, if specifiefd, aspirational and threshold				
Objectives	Targeted Observable(s)	Physical Parameter(s) Required	Rate of Change Accuracy (parameter/yr)	Extent Observed to Determine the Rate of Change	Latency (days)	Repeat Frequency (days)	Repeat Duration (months)
			95% Confidence				
How is climate change effecting the structure of boreal forests?	Vegetation Structure	Vegetation Height	1m/yr 2m/yr	100 sq km 50 sq km	30 60	160 365	6 6

SATM - example

Consolidated Science and Application Objectives → **Geophysical Parameters** → **Data Product Requirements**

Science and Applications			Level 3 or 4 Product	Level 3 or 4 Spatial Requirements Provide three requirements: from the Decadal Survey, if specififed, aspirational and threshold				
Objectives	Targeted Observable(s)	Physical Parameter(s) Required		Observed Area	Coverage (%)	Smallest Feature Resolution (m)		Sampling Distance (m)
						Horizontal	Vertical	
How is climate change effecting the structure of boreal forests?	Vegetation Structure	Vegetation Height	3-D (x,y,z voxels) Canopy Cover Fraction (CCF)	Forest cover north of 45°	100% 30%	10m tree stand 20m tree stand	NA	3m 7m

SATM - example

Consolidated Science and Application Objectives → **Geophysical Parameters** → **Data Product Requirements**

Science and Applications			Level 3 or 4 Product	Level 3 or 4 Temporal Requirements Provide three requirements: from the Decadal Survey, if specififed, aspirational and threshold				
Objectives	Targeted Observable(s)	Physical Parameter(s) Required		Rate of Change Accuracy (parameter/yr)	Extent Observed to Determine the Rate of Change	Latency (days)	Repeat Frequency (days)	Repeat Duration (months)
				95% Confidence				
How is climate change effecting the structure of boreal forests?	Vegetation Structure	Vegetation Height	3-D (x,y,z voxels) Canopy Cover Fractio (CCF)	0.15/yr 0.2/yr	100 sq km 50 sq km	30 60	160 365	6 6

SATM - example

Consolidated Science and Application Objectives → **Geophysical Parameters** → **Data Product Requirements**

Science and Applications			Level 3 or 4 Product	Level 3 or 4 Temporal Requirements Provide three requirements: from the Decadal Survey, if specififed, aspirational and threshold				
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				95% Confidence				
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SVT Incubation study next step

- **Survey distribution: ASAP**
- **Survey completion: 4 Aug 2020**
- **Collate survey inputs into SATM**
- Revised SATM: August 30, 2020
- Final SATM: October 30, 2020