The Vegetation Three-dimensional Structure, Biomass and Disturbance Advanced Mission Concept Study

A vegetation structure community developed mission concept – Prior to the Decadal Survey

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GSFC

Introduction

- The magnitudes and distributions of terrestrial carbon storage along with changes in sources and sinks for atmospheric CO_2 due to land use change remain the most significant uncertainties in Earth's carbon budget.
- These uncertainties severely limit accurate terrestrial carbon accounting; our ability to evaluate terrestrial carbon management schemes; and the veracity of atmospheric CO_2 projections in response to further fossil fuel combustion and other human activities.
- To address these critical uncertainties, NASA's Science Plan for 2007–2016 calls for "measurements of vegetation height and profiles of three-dimensional ecosystem structure to estimate aboveground biomass and carbon stocks with greatly reduced uncertainties and to characterize species habitats in ways that will enable exploration of fundamental controls on biodiversity."
- NASA HQ called for a study to combine a Multibeam Lidar and a P-band SAR to provide the key measurements to answer the science questions.

An Advanced
Earth Science Mission Concept Study for Vegetation 3D Structure, Biomass and Disturbance
Concept Study #1

for NASA HQ
by
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Science Question

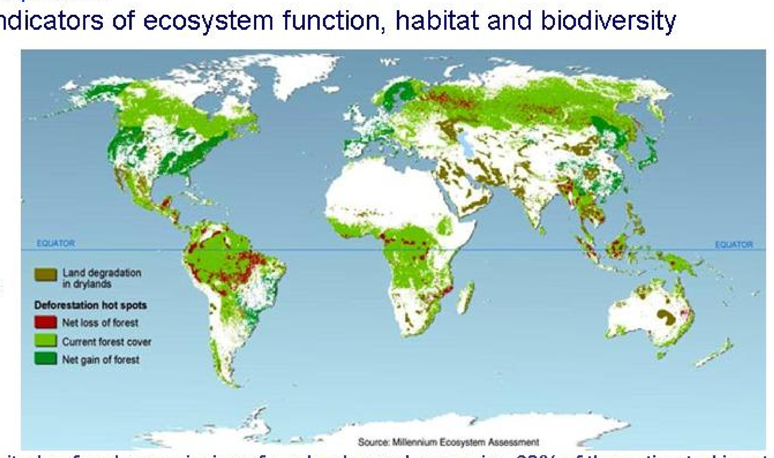
How are the Earth's carbon cycle and ecosystems changing, and what are the consequences for the Earth's carbon budget, ecosystem sustainability, and biodiversity?

The question requires measurements of three-dimensional vegetation structure to estimate:

(1) Carbon in Aboveground Vegetation
(2) Ecosystem Properties
- Structural indicators of ecosystem function, habitat and biodiversity

The map shows areas with a canopy cover of at least 40% by woody plants taller than 5 meters

The carbon and ecosystem structure implications of these dramatic changes are poorly quantified



Uncertainty in the magnitude of carbon emissions from land use changes is ~60% of the estimated input

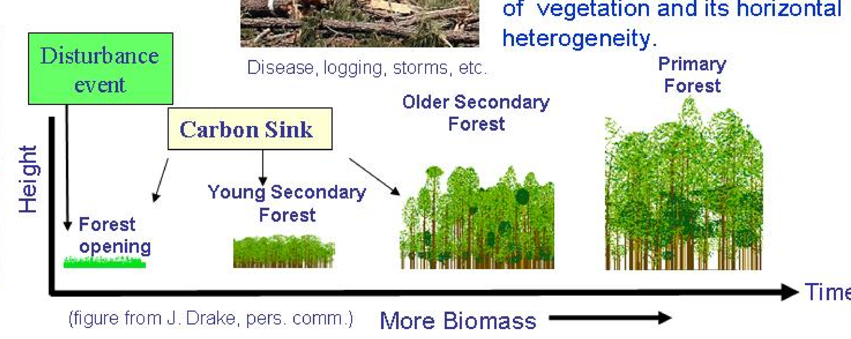
Science Question Components
Carbon in Aboveground Vegetation

Both human-induced and natural disturbance are major driving forces that determine the transition of forest stands, landscapes, and regions from carbon sink to source and back.

Disease, logging, storms, etc.

Climate and human-induced ecosystem changes are reflected strongly in the vertical height and density distribution of vegetation and its horizontal heterogeneity.

Fire

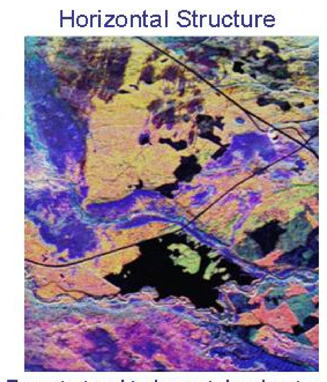


(figure from J. Drake, pers. comm.)

Science Question Components
Ecosystem Properties

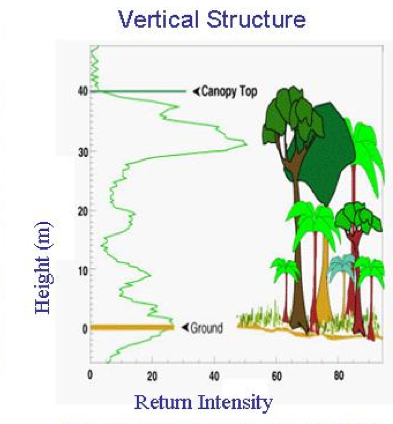
Changes in landscape spatial heterogeneity - vegetation type, height profiles and biomass relate strongly to ecosystem state and condition.

Horizontal Structure



Forests tend to be patchy due to natural and human disturbance. In this radar image from Canada there is evidence of fires (dark areas at top) and logging (e.g.,black features in center)

Vertical Structure



The vertical dimension provides key insight into ecosystem state and function based on the heights of canopy and understory

Ecosystem structure may change in response to climate. Top – change in tree form from bush to erect Bottom – new species appearing in the understory of this larch forest in Siberia

Science Rationale
Mission Science Objectives

1) Develop globally consistent and spatially resolved estimates of aboveground biomass and carbon stocks.
2) Make globally consistent and spatially resolved measurements of vegetation vertical structure to understand changes and trends in terrestrial ecosystems and their functioning as carbon sources and sinks.
3) Characterize and quantify the three-dimensional structural response to disturbance.
4) Quantify changes in terrestrial carbon sources and sinks resulting from disturbance and recovery.
5) Characterize habitat structure for biodiversity assessments.

Science Rationale
Measurement Overview

- Two complementary technologies meet the science requirements.
  - Multi-Beam Lidar
  - P-Band SAR
- Both are sensitive to vegetation vertical structure as documented by science results from:
  - Extensive airborne measurements (GSFC LVIS, JPL AirSAR)
  - ICESat and SIR-C/SRTM space-borne measurements.

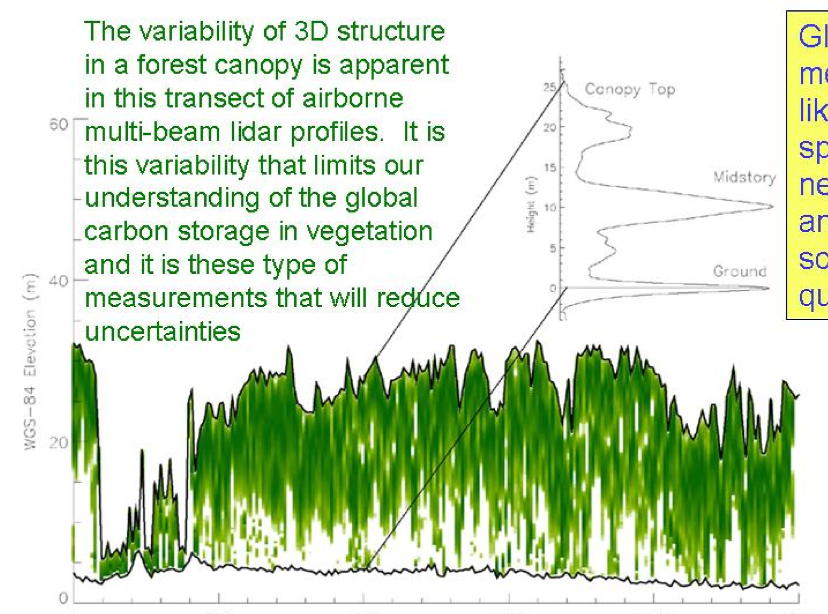
Measurements to be Made
Summary Capabilities

Measurement	Multi-Beam Lidar	P-Band SAR
Vegetation height (25 m res., ± 1 m)	Yes	No
Within canopy profiles, 2-3 m vertical resolution	Yes	No
Contiguous Biomass (100 m resolution, 10Mg/ha or +20%)	No, estimates possible through interpolation, at 1 km scale	Yes, up to ~200 Mg/ha
Annual Biomass Change (1 m res. , precision 2-4 tons)	No, however detailed change at specific locations	Yes, 45 day repeat
Re-visit time monthly to seasonal	Yes, however only for limited locations	Yes, globally
Reduce height measurement uncertainty caused by topography	Yes, use ~25 m footprints	No

Science Rationale
Instrument Rationale

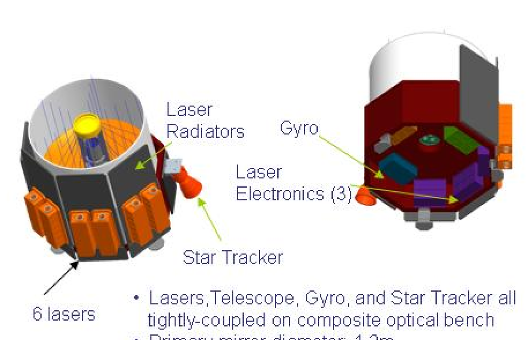
The variability of 3D structure in a forest canopy is apparent in this transect of airborne multi-beam lidar profiles. It is this variability that limits our understanding of the global carbon storage in vegetation and it is these type of measurements that will reduce uncertainties

Global measurements like these from space are needed to answer the science question



Source: http://lvis.gsfc.nasa.gov/

Multi-Beam Lidar Instrument Concept



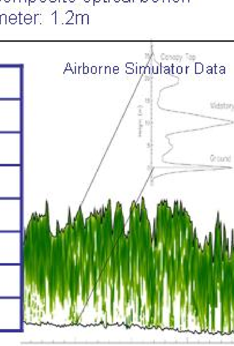
- Lasers,Telescope, Gyro, and Star Tracker all tightly-coupled on composite optical bench
- Primary mirror diameter: 1.2m

Features of the Instrument Concept
- Nadir-pointed Multi-Beam Lidar (1064 nm)
- 3- beams spaced nominally 5 km across-track
- 25 m laser footprint, 30 m along track spacing
- Multi-Beam Lidar operates as a sampler and will illuminate ~5(10)% of the Earth's land surface after 3(6) yrs.
- Expected Multi-Beam Lidar Lifetime = 6+ years
  - Laser tested to 5 B shots.
  - Diodes tested to equivalent of 3 years of operations (so far) with <1 % degradation.
- Range Resolution:
  - 3 cm (bare ground), 1 m (vegetation)
- Geolocation accuracy: 10m horiz., < 0.1 m vertical

Performance Data

Mass	265 kg
Power (peak)	336 W
Power (standby)	280 W
Power (avg)	336 W
Data Rate (peak)	4.8 Mbps
Data Rate (avg)	0.8 Mbps
Compression	2:1 lossless
Duty Cycle	35%

Airborne Simulator Data

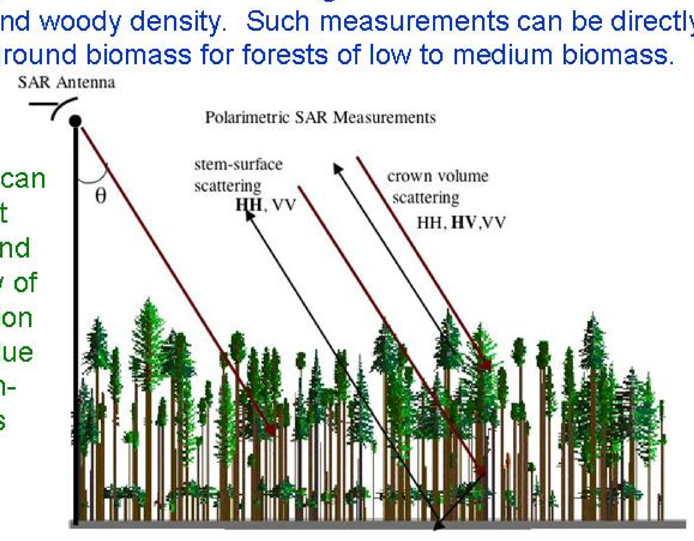


Technology Development Needs
- Laser transmitter is currently at TRL 5:
  - GSFC-designed HOMER laser tested to full flight performance requirements (output power, rep rate, beam quality, efficiency, and lifetime)
  - All components space qualified (TRL 6 or higher)
  - Testing of laser ETU in FY07 will verify the Multi-Beam Lidar perfomance in a relevant environment (vibration, thermal vacuum, etc.) → TRL 6.
  - Recent flight laser re-packaging effort resulted in ~40 kg of mass savings (265 kg → 225 kg).

Science Rationale
Instrument Rationale

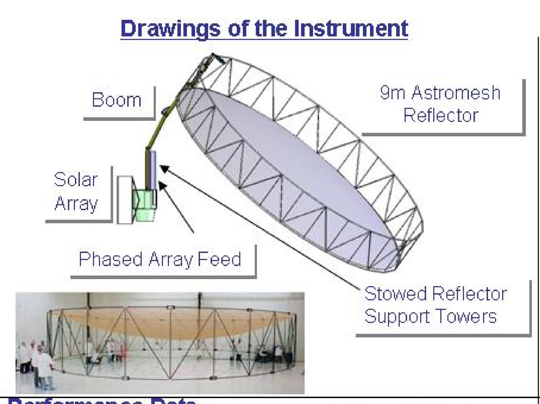
SAR illuminates the vegetation with microwave energy at an angle that interacts with vegetation structure and the ground and senses the entire canopy volume and woody density. Such measurements can be directly related to aboveground biomass for forests of low to medium biomass.

SAR measurements can be performed in most weather conditions and provide the capability of mapping the vegetation cover and changes due to natural and human-induced disturbances frequently.



P-Band SAR Instrument Concept

Drawings of the Instrument

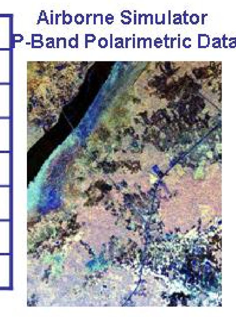


Features of the Instrument Concept
- Pointing: 25° cross-track (right) of nadir
- P-Band (435 MHz), 6 MHz Bandwidth
- Polarimetric (HH,HV,VH,VV)
- 25° illumination angle
- 62 km swath
- 100 m resolution (20 looks)
- Reflector Diameter: 9 m
- Reflector Width: 7 m
- Geolocation Accuracy: ~ 10 m
- Calibration: 1 - 1.5 dB absolute, 0.5 - 1.0 relative
- Noise Equivalent σ^0: < -30 dB

Performance Data

Mass	274 kg
Power (peak)	911 W
Power (standby)	93 W
Power (avg)	175 W
Data Rate (peak)	93 Mbps
Data Rate (avg)	9.3 Mbps
Compression	None
Duty Cycle	10%

Airborne Simulator P-Band Polarimetric Data



Technology Development Needs
- No technology development required
- Astromesh Antenna technology provides 10-15 year lifetime (TRL 9)
- Phased Array Feed (TRL 6)
- Heritage:
  - MBSat 12-meter reflector
  - INMARSAT 9-meter reflector

Summary

- Multi-Beam Lidar samples fused with synoptic P-Band SAR data can provide accurate, high-resolution vegetation structure, biomass, and disturbance estimates to resolve large uncertainties in the carbon budget and improve understanding of habitat and biodiversity.
- This study presents three feasible mission concept options that meet the science requirements for developing vegetation structure, biomass, and disturbance data products with global coverage.
- By reducing current large uncertainties about vegetation structure, biomass, and disturbance, this mission will:
  - Provide a substantially stronger basis for terrestrial carbon accounting and carbon management;
  - Improve projections of CO_2 and CH_4 increases in response to further fossil fuel use, land use change, and other human activities; as well as
  - Yield new insights about global habitat and associated biodiversity.

VEG3D Future

- The NRC Decadal Survey called for a combined multibeam lidar and interferometric SAR (InSAR) mission to address science objectives for Deformation of the Earth, Ecosystem Structure and Dynamics of Ice (DESDynI).
- The mission concept preserves the ~25m footprint multibeam lidar but calls for shorter wavelength L-band radar to serve as an interferometer to obtain surface deformation measurements
- Strict orbit requirements for InSAR measurements may limit lidar sampling and fusion with the radar measurements over vegetation
- Work is now on-going to develop an appropriate mission concept and determine how best to use L-band radar and/or InSAR along with the multibeam lidar for biomass and ecosystem structure related measurements.