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# Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI)

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*Abstract*—The National Research Council Earth Science Decadal Survey, Earth Science Applications from Space, recommends that DESDynI (Deformation, Ecosystem Structure, and Dynamics of Ice), an integrated L-band InSAR and multibeam Lidar mission, launch in the 2010–2013 timeframe. The mission will measure surface deformation for solid Earth and cryosphere objectives and vegetation structure for understanding the carbon cycle. InSAR has been used to study surface deformation of the solid Earth and cryosphere and more recently vegetation structure for estimates of biomass and ecosystem function. Lidar directly measures topography and vegetation structure and is used to estimate biomass and detect changes in surface elevation. The goal of DESDynI is to take advantage of the spatial continuity of InSAR and precision and directness of Lidar. There are several issues related to the design of the DESDynI mission, including combining the two instruments into a single platform, optimizing the coverage and orbit for the two techniques, and carrying out

the science modeling to define and maximize the scientific output of the mission.<sup>1,2</sup>

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<sup>1</sup> \_\_\_\_\_

<sup>1</sup> 1-4244-1488-1/08/\$25.00 ©2008 IEEE.

<sup>2</sup> IEEEAC paper #1223, Version 5, Updated December 17, 2007

## 1. INTRODUCTION

In 2004, at the request of NASA, NOAA, and the USGS, the National Research Council appointed the Committee on Earth Science and Applications from Space to develop consensus recommendations for Earth and environmental science and applications from space. In 2007, the final report was published and included a recommendation for a Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI) mission [1]. DESDynI is an L-band InSAR and laser altimeter for studying surface and ice sheet deformation for understanding natural hazards and climate, and vegetation structure for ecosystem health.

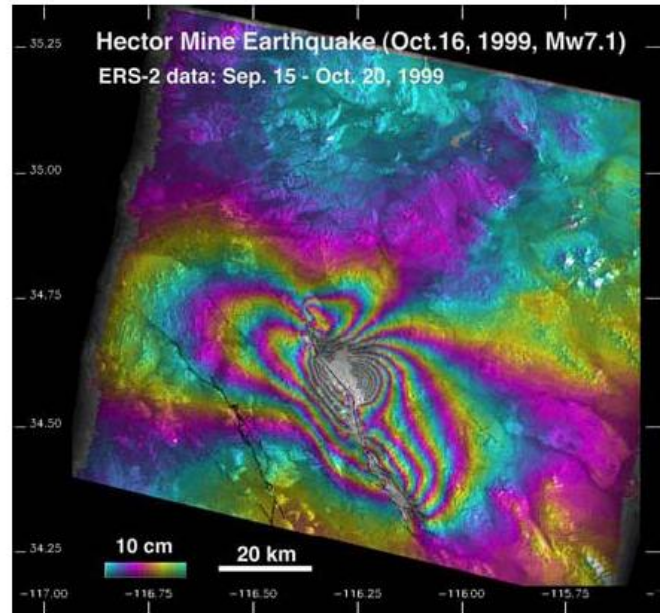
DESDynI addresses many of the scientific objectives assigned high priority by the decadal survey. It will measure the height and structure of forests, changes in carbon storage in vegetation, ice sheet deformation and dynamics, and changes in Earth's surface and the movement of magma. These measurements will improve our understanding of the affects of changing climate and land use on species habitats and atmospheric CO<sub>2</sub>. DESDynI measurements will also facilitate the monitoring of species habitats, understanding the response of ice sheets to climate change and the impact on sea level, and forecasting the likelihood of earthquakes, volcanic eruptions, and landslides.

## 1. SCIENCE

NASA hosted a workshop in July 2007 to assess the DESDynI mission, articulate the expected scientific return from DESDynI, and recommend next steps for the mission [2]. The mission will be used to improve forecasts of the likelihood of earthquakes, volcanic eruptions, and landslides, help scientists understand the effects of changing climate and land use on terrestrial carbon storage, fluxes of carbon dioxide to the atmosphere, and species habitats, and study the response of ice sheets to climate change and their impact on sea level. The primary mission objectives for DESDynI are to:

- (1) Determine the likelihood of earthquakes, volcanic eruptions, and landslides.
- (2) Predict the response of ice sheets to climate change and impact on sea level.
- (3) Characterize the effects of changing climate and land use on species habitats and carbon budget.

And as an application:



**Figure 1. Surface deformation map of the 1999 Hector Mine earthquake, derived from ERS radar data. Each color fringe represents 10 cm of ground displacement from the earthquake.**

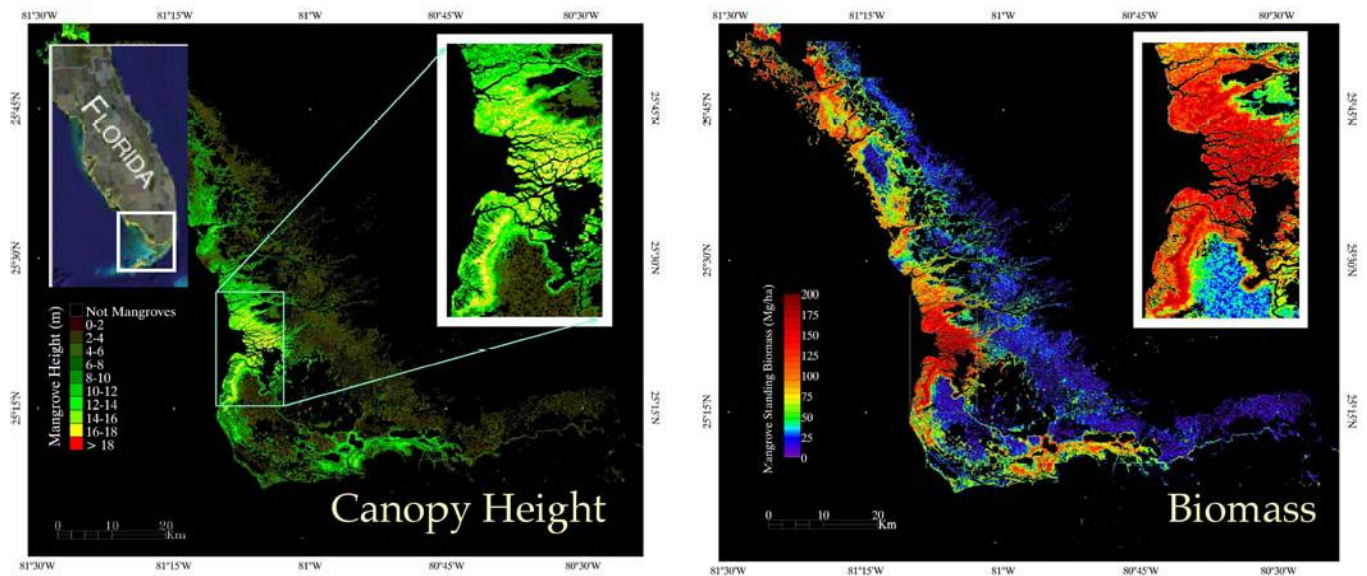
- (4) Monitor the migration of fluids association with hydrocarbon production and groundwater resources.

The science objectives of DESDynI for solid Earth, cryosphere, and ecosystems result in a number of requirements for measurement of solid Earth and ice sheet surface deformation, forest structure, and ice thickness and kinematics. Level 1 requirements for the mission have been drafted, and from these requirements the instrument and spacecraft requirements must be developed. A summary of the science objectives and level 1 requirements follows.

### *Solid Earth*

DESDynI will be used to help define how we prepare for, mitigate against, and respond to major geohazards. US annualized losses from earthquakes are \$4.4B/yr [3], yet current hazard maps have an outlook of 30–50 years over hundreds of square kilometers [4] making prioritization of retrofitting difficult. Volcanic eruptions destroy cities and towns, eject ash clouds that disrupt air travel, and disrupt regional agriculture. Recurrent flood hazards threaten civilian safety and commerce worldwide. Mississippi River flooding in 1993 caused \$15–20 billion damage and displaced 70,000 people. The 2004 tsunami in southeast Asia killed over 140,000 people. Sea level change, land subsidence, and landslides are becoming more problematic with development in high-risk areas. The New Orleans levee system is subsiding at an average rate of 8 mm/yr [5], which must be understood and factored into reconstruction plans.





**Figure 2. Mangrove forest height and inferred biomass density from SRTM calibrated with Lidar (ICESat/GLAS and airborne) and field data. Mangroves contribute 11% of global total carbon export to the ocean. Mangrove forests are in danger of being lost entirely due to economic development and sea level rise. 35% of mangrove forests have disappeared and 60% could be lost by 2030 [6].**

Precise measurement of surface deformation (Figure 1) coupled with models can improve assessment of risk from natural hazards, which ultimately can minimize loss of life and destruction of property. Forecasting of earthquakes, volcanoes, and landslides is greatly improved by an understanding of how the surface deforms and moves, which can be used to infer subsurface processes. Earthquake risk assessment requires knowledge of the mechanisms that control both transient and steady state aseismic fault slip.

Observation of pre-slip can aid in mitigating losses from landslides. Measurement of uplift and subsidence yields insights into the size, location, and movement of magma within volcanic chambers. Detailed crustal deformation measurements have been crucial to better understanding these natural hazards, yet only a small fraction of the world's active volcanoes and faults are instrumented. DESDynI provides the opportunity to image the deformation field associated with these events and infer the causative deformation sources at depth globally and systematically.

The first requirement of solid Earth for the DESDynI mission is to characterize the nature of deformation at plate boundaries and the implications for earthquake hazards by measuring surface deformation and surface disruption [7]. Measurement of surface deformation is used to discriminate between faults and assign potential hazard. It requires 3-dimensional (vector) global coverage of actively deforming areas with 100 m resolution imagery accurate to 5% of the rate of the deforming zone or to 1 mm/yr. 200 km width

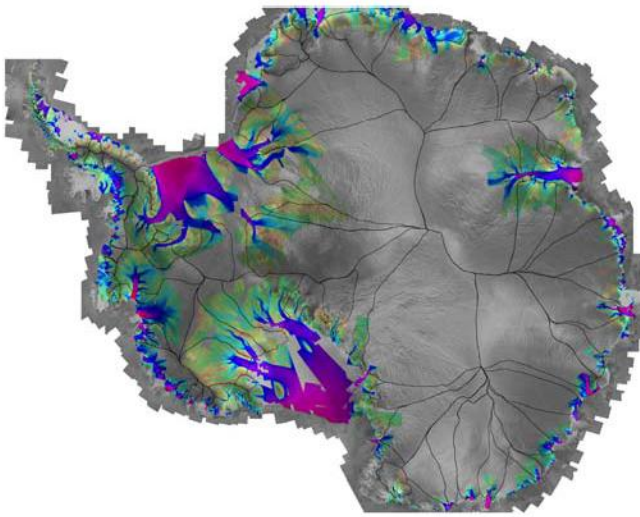
imagery across the deforming boundary is required as is unaliased temporal sampling with week-timescale measurements, particularly immediately following an event. Measurement of surface disruption with 20 m resolution over a 400 m zone across the fault is required to infer the mechanical properties of the earthquake fault zone.

The second requirement for solid Earth for DESDynI is to characterize how magmatic systems evolve in order to understand under what conditions volcanoes erupt. Again, this requires measurement of surface deformation, this time to infer the volume of magma in the chamber and potential hazards. This requires coverage of the Earth's active volcanoes, which requires an initial exploratory survey of all of the volcanoes to discover which are deforming. Again, 3-dimensional (vector) deformation with 100 m imagery is required. Measurement of surface disruption at 20 m resolution throughout the area of eruption is required to infer the volume of magma released.

### *Ecosystems*

The rate of increasing atmospheric CO<sub>2</sub> over the past century is unprecedented, at least over the last 20,000 years [8]. Vegetation ecosystems, especially forests, store carbon, thus changes in these systems impact the global carbon budget and the amount of CO<sub>2</sub> in the atmosphere. Major sources of uncertainty in global carbon budgets derive from large errors in the current estimate of carbon storage in vegetation and changes in land cover [9] Disturbances, either from natural phenomena such as fire or wind or from





**Figure 3. Mosaic of ice velocities determined from 10 years of ERS 1/2 data in Antarctic overlaid on a radar map.**

human activities such as forest harvest and subsequent recovery, complicate the quantification of carbon storage and release. The resulting spatial and temporal heterogeneity of terrestrial biomass coupled with a lack of biomass surveys for most of the world make it difficult to estimate terrestrial carbon stocks and dynamics.

DESDynI will provide globally consistent and spatially resolved estimates of vegetation structure from which aboveground biomass (e.g. Figure 2) and ecosystem function can be derived [6, 10, 11]. These structure and biomass estimates will be used to characterize and quantify changes in terrestrial carbon sources and sinks resulting from disturbance and recovery. They will also be used to characterize forest structure for biodiversity assessments.

DESDynI is particularly suited for quantifying vegetation in three dimensions yielding vegetation height, vertical profiles, and disturbance recovery patterns that are required to characterize species habitat and assess ecosystem health. Accurate measurements of vertical structure will be used to improve models of photosynthetic function and ecosystem productivity. These parameters are used to couple feedback effects between the terrestrial part of climate change in general circulation models (GCMs). USDA Forest Service fire spread models require structural inputs such as canopy height, canopy cover, vertical biomass profiles, and canopy base height. The destructive fires of 2007 in southern California highlight the need for improved fire spread models for forest fire preparedness and mitigation.

Developing globally consistent and spatially resolved estimates of above ground biomass and carbon stocks

requires observation of the global vegetated cover with 100 m spatial resolution accurate to 10 Mg/hectare or to within 20% at least once per year during the growing season [9]. Understanding changes and trends in terrestrial ecosystems and their functioning as carbon sources and sinks requires observation of global vegetated cover with 100 m spatial resolution. Measurements must be accurate to 2–4 Mg/ha/year or to within 20% of the change and must be made monthly to seasonally over the life of the mission, which must have a minimum duration of 5 years. Characterizing habitat structure for biodiversity assessments requires a horizontal resolution of better than 25 m and a vertical resolution of 2–3 m of the canopy profile. Achieving these measurement goals requires the combination of the multibeam full-waveform Lidar with radar polarimetry.

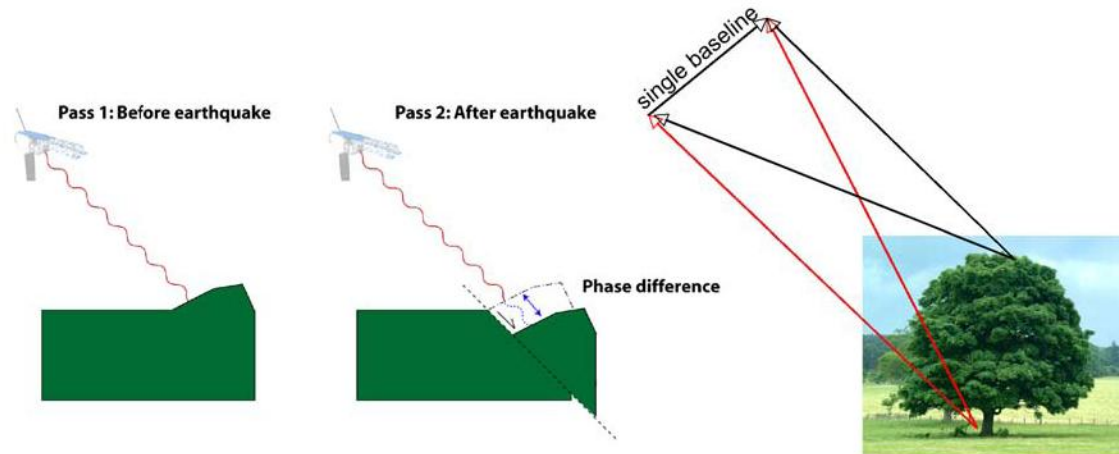
### *Cryosphere*

Ice sheets and glaciers are experiencing dramatic changes that have the potential to raise sea level substantially in the coming decades (Figure 3). Despite the scientific and societal importance, and their sensitivity to climate change, they remain one of the most under-sampled components of the Earth System. Recently flow rates of outlet glaciers around many parts of Greenland and Antarctica have increased significantly, more than doubling in some cases. These accelerations and increased melt rates have been causing the glaciers and ice sheet margins to thin by as much as meters to tens of meters per year, as their ice is lost to the surrounding seas. These phenomena raise the question of ice sheet stability and the potential of these ice sheets to contribute to relatively rapid rises in sea level. As a result, the authors of the Decadal Survey [1] identified as one of their highest-priority questions: “Will there be a catastrophic collapse of the major ice sheets, including Greenland and West Antarctica, and if so, how rapidly will that occur? What will be the pattern of sea level rise as a result?”

DESDynI would help address these questions by providing comprehensive observations of ice sheet surface dynamics, which are directly related to ice sheet stability. The interferometric radar would precisely measure surface velocities of the rapidly changing outlet glaciers, enabling improvements in ice sheet modeling capabilities to facilitate improved projections of ice sheet contributions to sea level rise in response to the changing climate

Sea ice is another component of the Earth system that is changing rapidly and in ways that can affect climate worldwide. Ice cover in both the Arctic and Antarctic play a critical role in the global climate system by modulating the exchange of moisture and energy between the ocean and the atmosphere, and influencing oceanic and atmospheric circulation. In the Arctic, the ice cover has been diminishing





**Figure 4. Illustration of how Interferometric Synthetic Aperture measures surface deformation with a zero-length baseline (left panel). The phase of the radar wave changes between two passes if a point on the ground moves. Measurements from a finite baseline (right panel) can be used to measure forest structure because the interferometric phase return from various altitudes within trees (the top and bottom of the tree are shown for illustration) is different for different locations of the satellite forming the baseline.**

substantially, while in the Antarctic there have not been substantial changes. Understanding the interactions among the ice, ocean, and atmosphere, and their future behavior requires comprehensive observations of sea ice extent, concentration, and thickness. These are best derived from multiple satellite observations from existing and future missions such as DESDynI, AMSR-E, SSM/I, Cryosat, ICESat, and ICESat-II.

InSAR on DESDynI will augment those observations by providing detailed information on the mechanisms of deformation and transport of polar sea ice cover. This information can improve structural models of sea ice behavior to help understand the interactions among the ice, ocean, and atmosphere, and how they may behave in the future. If the Lidar is designed with sufficient precision, it can be used to provide ice thickness information that is critical to understanding its present and future behavior. Understanding our cryosphere requires measurement of surface deformation as well as thickness of sea ice. The objective is to quantify the interactions among ice masses, oceans, and the solid Earth and their implications for sealevel change [7]. This requires global coverage of ice masses and the measurement of surface displacement to quantify ice fluxes in order to infer global mass balance. Surface displacements must be measured on rapidly moving ice masses with horizontal velocities accurate to the greater of 2 m/yr or 10% of the total velocity. Vertical subsidence must be measured to 5 mm. Weekly observations are required to quantify temporal changes at 100 m resolution.

The second requirement is to quantify sea ice mass balance and how it is changing over the Arctic and Southern Oceans at inter-annual timescales over a minimum of 5 years. From

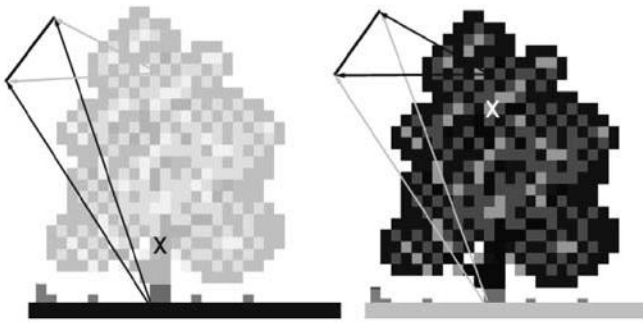
this follows the need to 1) quantify changes in sea ice thickness by measuring sea ice freeboard to a vertical accuracy of 15 cm with a spatial resolution of 25 m, and 2) quantify how sea ice motion and circulation are changing at kilometer scales with 100 m resolution. The latter requires daily time scales to provide uninterrupted time series to cover advance and retreat of seasonal/perennial ice cover over a minimum of 5 years.

## 2. INSTRUMENTS

DESDynI's instruments are an L-band radar and a multi-beam Lidar. The radar instrument will be used to measure surface deformation of the solid Earth and cryosphere and will be used in other modes to study ecosystems. The Lidar will be used primarily to support the ecosystem science objectives of DESDynI, but may be used for studying ice sheet mass balance, and possibly the solid Earth.

**Table 1. Radar operating modes for DESDynI**

Mode	Application
Strip Map (single- or dual-pol)	Volcanic, earthquake, ice sheet deformation
ScanSAR (single- or dual-pol)	Tectonic deformation
Full-polarimetry (strip map)	Ecosystems and carbon stocks
Zero baseline	Surface Deformation
Finite baseline	Vegetation Structure and biomass



**Figure 5.** Using single polarization finite baseline interferometry the average phase, somewhere in the tree, can be determined (A). A polarization such as VVVV might illuminate the ground more than the volume, as suggested by the darker ground surface in A, drawing the phase center down to the X shown in Figure 5A. A polarization such as HVHV might illuminate the volume more than the ground drawing the phase center closer to the top of the canopy as in B. Multiple polarizations, in effect add contrast and can be used to estimate structure from the systematic changes in InSAR phase and coherence as a function of polarization.

#### *Radar*

The DESDynI radar instrument is an L-band (1.2-GHz) synthetic aperture radar (SAR) system with multiple polarizations that can be operated in several modes (Table 1). The radar instrument will be operated as repeat pass Interferometric Synthetic Aperture Radar (InSAR) to measure surface deformation, and ice sheet dynamics (Figure 4, left panel). An InSAR satellite passing over a location before and after an event, such as an earthquake, tectonic deformation, volcanic inflation, or ice sheet motion, at exactly the same point in inertial space (zero baseline) can measure how the ground shifts between passes, producing a radar interferogram. The phase of the radar wave changes between two passes if a point on the ground moves. An InSAR image of the point-by-point phase difference of the wave on the surface is used to create a map of the movement of the surface over time. The radar instrument can take observations through cloud cover, without sunlight, and can measure sub-centimeter changes. The radar phase differences between the ends of a nonzero baseline are proportional to the difference between the arrival times of the waves at each end of the baseline. For each component of a vegetated surface (leaves, branches, trunks, ground) this radar phase difference, called the interferometric phase, is therefore proportional to the height of that component (Figure 4 right panel). Combined with a related quantity called the interferometric coherence, the interferometric phase can be used to measure ecosystem structure using finite baseline interferometry (Ref. C). One way to approach this is to carry out campaigns during the mission that offset the orbit to provide the finite baselines required for estimating forest structure.

It has been shown that a single, finite-baseline InSAR phase-coherence pair are insufficient to estimate the complex structure of forests [12]. The single-baseline “underdeterminedness” has been addressed by various researchers using external calibration in the form of field [e.g. 13] and/or Lidar [6] measurements. It has also been addressed by using multiple baselines [e.g. 14], multiple frequencies [15], and/or multiple polarizations [e.g. 16]. In various operating modes, DESDynI can realize all of these modes of structure estimation except the multifrequency mode, which might be accessible via collaboration with other missions. For example, InSAR measurements at different polarizations will be used to estimate vegetation structure and biomass. Figure 5 shows schematically that InSAR at different polarizations changes the phase (and the coherence) of the InSAR measurement [17]. Multipolarization interferometry is a method of adding contrast between the ground and the tree volume and can be used to estimate vertical forest structure by the systematic differences in interferometric response to each polarization [16], as suggested in Figure 5. Each phase is weighted by how strong the return is. Some polarizations are sensitive to the ground, for example, ground bounce HH-HH and the direct return VV (Figure 5A), while other polarizations are sensitive to volume such as the cross polarizations HV-HV (Figure 5B).

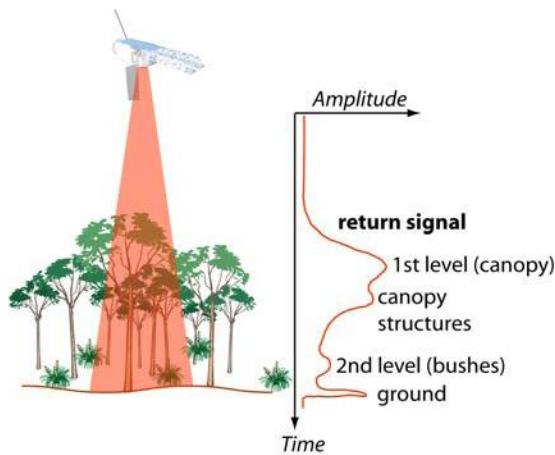
The radar instrument operates in the L-band and will have two sub-bands separated by 70 MHz for ionospheric correction. The split spectrum techniques are used to correct phase delays introduced by ionospheric propagation. The mission is also designed with a sun-synchronous dawn-dusk orbit to minimize ionospheric effects. The ionosphere is most quiet at dawn. Some DESDynI radar data will be affected by ionospheric distortions, including Faraday rotation, phase delays, and scintillation. Ongoing research into correction for Faraday rotation appears promising [18]. Indications are that it will be possible to correct data collected in fully polarimetric mode. Research into scintillation effects is currently focused on determining the expected frequency of occurrence and severity of such events at the 6 am and 6 pm observation times of DESDynI.

#### *Lidar*

The DESDynI Lidar instrument is a multiple-beam Lidar operating in the infrared (about 1,064 nm) with a spatial resolution of 25 meters producing a spatial resolution of forest canopy height of 1 m. Lidar (Light Detection and Ranging) uses light in the visible spectrum transmitted in a narrow beam. It allows detailed observations of vegetation structure in tree canopies and accurate measurement of ice sheets, glaciers, and topography [19].

Lidar systems transmit pulses of laser light downward and receive various reflections from the surfaces of leaves and other forest elements, including the ground (Figure 6). The round-trip travel times are directly related to the heights of





**Figure 6. The return signal waveform from Lidar contains information on the height and structure of forest canopy.**

the reflecting vegetation elements. The profile of vegetated surfaces resulting from a time sequence of reflections can be used in an empirical regression to field data to derive biomass. Moments of the profile, such as mean height, are most often used to establish correlative relations with field biomass. The multibeam laser altimeter accurately measures the distance between the canopy top and bottom elevation in forests. It also measures the vertical distribution of intercepted surfaces and the size and distribution of vegetation components within the vertical distribution.

#### 4. MISSION DESIGN

DESDynI takes advantage of the precision and directness of the Lidar with the global spatial coverage of the radar. The radar and Lidar measurements for ecosystem studies need to be made in close proximity in time enabling cross calibration and validation. Forest growth, budding, and dropping of leave occur on fairly short timescales, thus each of the measurements must be made within a few weeks of the other [1]. InSAR and Lidar measurements have similar mission requirements. For example, a sun-synchronous dawn-dusk orbit is required for the radar measurements to minimize effects of the ionosphere and for the Lidar to reduce effects of reflected solar radiation, especially in the tropics. The ionosphere is most quiet and the minimum cloud cover is at dawn. However, combining science and measurement objectives in addition to two instruments onto a single spacecraft results in competing design trades. We believe that a solution exists which yields a mission that meets Earth science objectives including those of Solid Earth, Cryosphere, and Ecosystems. The following outlines some of the competing differences between the InSAR and Lidar science measurements.

For a vegetation Lidar mission a higher inclination polar orbit is preferred, but for an ice Lidar mission a lower

inclination such as  $94^\circ$  is preferred. The  $98^\circ$  inclination planned for DESDynI maintains the sun-synchronous orbit and is acceptable for both the Lidar and InSAR measurements for this mission. The preferred orbit altitude for a Lidar instrument is a 400–600 km due to the need for increasing power and telescope aperture size with increasing altitude. The InSAR requires a higher orbit, preferably in the range of 700–800 km for swath coverage and to reduce atmospheric drag. A 600 km orbit is acceptable for both the InSAR and Lidar instruments; hence the orbit should be designed near this altitude.

A long (~90-day repeat) is desired for Lidar to provide full geographic coverage. The Lidar is a nadir-pointing instrument with a 25 m diameter beam spot size that produces distributed spot-beam ground tracks. InSAR, on the other hand, requires rapid repeats in order to observe deformation processes typically on weekly timescales. Discrimination between postseismic processes requires a 14-day repeat for a duration of at least two years in order to avoid aliasing and for a signal to emerge out of the errors [20]. Grounding line dynamics studies require that the repeat measurements be made out of cycle with the tides (7 and 14 days). In addition, rapidly changing targets, such as leaves moving in the wind, or rapidly moving ice measurements require short time scale repeat observation to minimize decorrelation. Week-timescale measurements, or an 8-day repeat orbit, result in a ground track spacing for the Lidar measurements of 350 km at the equator, which is not desirable for calibrating the radar measurements. A possible compromise is a 12-day repeat orbit in combination with off-nadir pointing for the Lidar instrument. This may achieve the needed Lidar coverage without undue compromise to the InSAR measurements. Unlike the Lidar instrument, the radar instrument looks to the side at a  $25\text{--}30^\circ$  angle, which means that the two measurements will not be made exactly coincident in time. However, as long as the radar instrument is collecting data, the measurements will be made within a few days or weeks of each other.

Competing trades between the need for near zero (less than 250 m offset) repeat pass radar interferometry for deformation studies and finite (0.6–1.5 km) baseline radar interferometry for vegetation structure estimates are workable by splitting the mission into campaigns. The ground track for DESDynI can be perturbed to provide the finite offsets needed for estimating vegetation structure, without drifting the orbit. At the beginning and end of the mission during northern summer a finite baseline campaign can be accomplished by cycling the spacecraft three-seconds ahead of normal orbit position and then back on eight-day centers for three months. Moving the spacecraft 3-seconds in its orbit will result in a 1.5 km offset to the ground track at the equator and acceptable but smaller offsets at higher latitudes. The 250 m tube will be maintained during this finite baseline campaign allowing the near-zero baseline science to be continued but now for two separate but consistent ground tracks, one the nominal



mission track and the other offset by 1.5 km. The impact to the mission will be increased temporal decorrelation due to a 16-day repeat vs. the desired 8-day repeat for the deformation science and an increase in Delta-V of 15–40 m/s. The main mission campaign will consist of the near-zero baseline fixed orbit with Lidar and ScanSAR on an 8-day repeat cycle and quad-pole radar measurements during the growing season. The mission can be designed in a similar manner, but for a 12-day orbit, to improve Lidar coverage.

Another mission scenario endorsed by the National Research Council Decadal Survey is to fly the InSAR and Lidar on separate platforms, which would allow both instruments to fly in orbits optimized for their key science objectives. This would ensure maximum data acquisition to meet discipline science requirements and opportunities for cross calibration activities.

Radar science measurements require collection, storage and downlink of large volumes of data. Relative to the radar the Lidar downlink requirements are minimal, and hence all of the collected Lidar data can be down linked. The mission is planned to observe the land and ice masses only, which cover 30% of the Earth's surface. Solid Earth, vegetation and cryosphere science requires observation of Earth's deforming zones, forested areas and ice sheets representing about 40% of the land surface. Therefore, it is not necessary to keep the radar instrument turned on continuously and this results a manageable data downlink strategy. There will still be a large amount of data, however (about 600 GB/day), thus a clear data processing and distribution strategy will need to be developed early in order to maximize the use of the data.

## 5. CONCLUSIONS

DESDynI will be the first mission to collectively study the solid Earth, the ice masses, and ecosystems systematically and globally. It uses L-band interferometric synthetic aperture radar and multibeam Lidar to achieve its objectives, which are to characterize the effects of changing climate and land use on species habitats and atmospheric CO<sub>2</sub>, predict the response of ice sheets to climate change and impact on sea level and forecast the likelihood of earthquakes, volcanic eruptions, and landslide. DESDynI will achieve these goals by measuring the height and structure of forests, changes in carbon storage and vegetation, ice sheet deformation and dynamics, and changes in the Earth's surface and the movement of magma. Mission compromises are possible that enable co-manifesting the InSAR and Lidar instruments and address the three science disciplines.

## 6. ACKNOWLEDGEMENTS

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## BIOGRAPHIES



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**Robert Treuhft** is a principal research scientist at the Jet Propulsion Laboratory, California Institute of Technology. From 1982-1987, he developed and published a model of tropospheric turbulence in wide use by the astronomical community. In 1991, he performed the first measurement of relativistic deflection

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**Bob Oberto** is a Senior Spacecraft Systems Engineer at NASA's Jet Propulsion Laboratory. He has served in a number of roles including the Principal Investigator of the NASA Exploration Design Team, a multi-NASA center design activity. Bob has been the Project Manager of the JPL Design Teams where he managed all

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**Waleed Abdalati** conducts research on high-latitude glaciers and ice sheets using satellite and airborne instruments. He has led or participated in 8 field expeditions to remote regions of the Greenland ice sheet and the ice caps in the Canadian Arctic. From 2000 to the present, he has been Manager of

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**H.H. "Hank" Shugart** received B.S. and M.S. degrees in Zoology from the University of Arkansas and a Ph.D. in 1971, also in Zoology, from the University of Georgia. He is a systems ecologist whose primary interests are in the dynamics of forest ecosystems. He has been the W.W. Corcoran Professor of Environmental

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**Mark Fahnestock** is from the University of New Hampshire. He received a BS degree in Geology from the University of Rochester in 1984 and a doctorate in Geology from the California Institute of Technology in 1991. Since then he has worked as a glaciologist investigating ice flow mechanics and surface conditions on the large ice sheets. His research covers many aspects of land-based ice. He has worked in Greenland and Antarctica on a variety of projects and participated in several Antarctic and Greenland field excursions. His recent interests focus on the controls underlying rapid ice flow and on atmospheric interactions that determine surface conditions on the large ice sheets. The primary tools for this work are satellite-derived and surface observations and interactions with ice sheet modelers.



**Ralph Dubayah** is a Professor in the Geography Department at the University of Maryland College Park, and a Fellow at the University of Maryland Institute for Advanced Computer Studies. His main research areas are landcover characterization and the land surface energy and water balances. He leads a NASA EOS Interdisciplinary Science Investigation (IDS) on the use of remote sensing for macroscale hydrological modeling. Most recently he is the principal investigator for the Vegetation Canopy Lidar (VCL), the first NASA Earth System Pathfinder (ESSP) mission, which will measure the three-dimensional structure of the Earth's topography and forests. He serves in various U.S. national organizations, including the Remote Sensing Committee of the American Geophysical Union (chair).