Radar and Lidar Measurement of Terrestrial Processes

PAGES 349–350

Earth's land surface is constantly changing and interacting with its interior and its atmosphere. In response to the interior, plate tectonics deform the surface, causing earthquakes, volcanoes, mountain building, and erosion—including landslides. These events can be violent and damaging. Forests, growing on the land surface, store carbon, which can be released into the atmosphere through logging and burning. Our ice sheets, sea ice, and glaciers are key indicators of our climate, and they have been undergoing dramatic changes. These land surface processes can be characterized and monitored from space using synthetic aperture radar (SAR) and light detection and ranging (lidar).

In 2007, the U.S. National Research Council's Committee on Earth Science and Applications From Space carried out a decadal survey [*National Research Council (NRC)*, 2007] to generate consensus recommendations from the Earth and environmental science and applications communities regarding a systems approach to space-based and ancillary observations. The committee recommended 17 missions. One of these, recommended in the top tier, is a mission called Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI), designed to measure changes in land, ice, and vegetation structure. The DESDynI concept consists of an L-band (24-centimeter wavelength) SAR designed to operate as an interferometric SAR (InSAR) and a multibeam lidar. Both instruments contribute to understanding natural hazards, carbon balance, forest use, and climate change.

Science Objectives

The primary mission objectives for DESDynI are to (1) determine the likelihood of earthquakes, volcanic eruptions, and landslides; (2) characterize the global distribution and changes of aboveground vegetation, biomass, and ecosystem structure; and (3) predict the response of ice masses to climate change and their impacts on sea level. DESDynI would be the first mission to systematically and globally study the solid Earth, ice masses, and ecosystems—all of which are sparsely sampled at present.

The precise measurement of surface deformation derived from DESDynI's InSAR (see Figure 1a) coupled with models would improve the assessment of risk from natural hazards, which ultimately can minimize the loss of life and destruction of property. Annualized losses in the United States from earthquakes are $5.3 billion per year [see *Federal Emergency Management Agency*, 2008], yet current hazard maps are limited to an outlook of 30–50 years at a coarse resolution of hundreds of square kilometers, which makes it difficult for targeted hazard preparedness and prioritization of retrofitting buildings and structures. Volcanic eruptions can destroy cities and towns, eject ash clouds that disrupt air travel, and disrupt regional agriculture. Sea level change, land subsidence, and landslides are becoming more problematic with development in high-risk areas. The forecasting of earthquakes, volcanoes, and landslides is greatly improved by an understanding of surface deformation and the inferred subsurface processes.

The rate of increase of atmospheric carbon dioxide (CO_2) over the past century is unprecedented for at least the past 150,000 years. Terrestrial ecosystems, largely in the form of forests, take up and store carbon; thus, changes in these systems affect the global carbon budget and the amount of the greenhouse gases CO_2 and methane in the atmosphere. A major source of uncertainty in global carbon budgets derives from large errors in the current estimate of carbon storage in forest vegetation. DESDynI would be used to measure vegetation structure (see Figures 1b and 1c) to understand changes and trends in terrestrial ecosystems and their functioning as carbon sources and sinks, and to characterize and quantify changes resulting from disturbance and recovery.

Vegetation height, vertical profiles, and disturbance recovery patterns are also required to characterize habitat and assess ecosystem health. These parameters can be used to couple feedback effects between terrestrial ecosystems and the atmosphere in general circulation models. The U.S. Department of Agriculture's Forest Service fire spread models require structural inputs such as canopy height, canopy cover, vertical biomass profiles, and canopy base height. The recent destructive fires of 2007 and 2008 in southern California highlight the need for improved fire spread models for forest fire preparedness and mitigation.

Ice sheets and glaciers are experiencing dramatic changes that have the potential to raise sea level substantially in the coming decades. Flow rates of outlet glaciers around many parts of Greenland and Antarctica have increased significantly in the past several decades, more than doubling the rate of loss of ice from those regions' great ice sheets in some cases. These accelerations and increased melt rates have been causing the glaciers and ice sheet margins to thin by as much as 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 of the potential impact of these changes on habitability of our planet, the *NRC* [2007] decadal survey identified the following as among Earth science's 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 time patterns of sea level rise as a result? DESDynI would provide comprehensive observations of ice sheet and glacier surface dynamics, which are directly related to their stability as a 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. Comprehensive observations of sea ice extent, transport, concentration, and thickness derived from multiple satellite observations, including DESDynI, will improve our understanding of the interactions between the ice, ocean, and atmosphere, and their future behavior.

Measurement Strategy

The DESDynI radar instrument, as defined by the decadal survey, is an L-band (1.2-gigahertz) SAR system with multiple polarizations that can be operated in

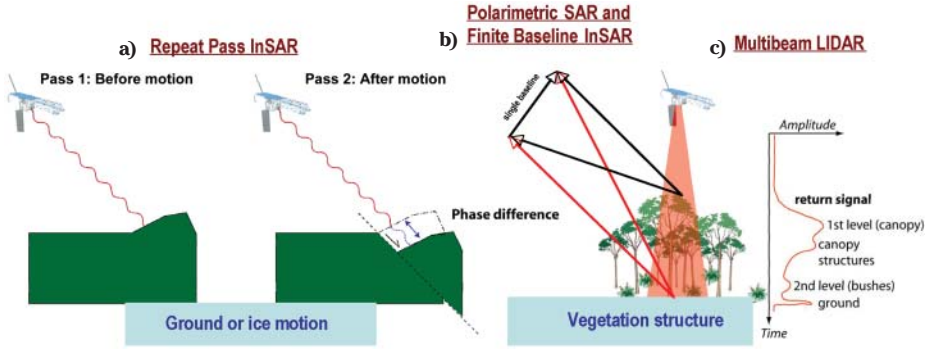

Fig. 1. DESDynI techniques: (a) Phase of radar wave changes between passes, creating a map of movement of over time. (b) Radar is used to estimate biomass and vegetation structure. (c) Lidar return signal contains information on height and structure of forest canopy.

several modes. The radar instrument would be operated as repeat pass InSAR to measure subcentimeter changes in surface deformation and ice sheet dynamics. The radar instrument could also be used to measure ecosystem structure using nonzero baseline interferometry, while radar backscatter at different polarizations would be used to estimate vegetation structure, biomass, and woody components of forests.

The DESDynI lidar instrument is a multiple-beam lidar operating in the infrared (about 1064 nanometers) with a proposed spatial resolution of approximately 25 meters and a forest canopy height accuracy of 1 meter. The multibeam laser altimeter accurately measures the distance between the canopy top and the bottom elevation in forests. The altimeter also measures the vertical distribution of intercepted surfaces and thus how vegetation components are arranged vertically. The smaller lidar footprint resolution reduces forest height errors caused by topography, and the multiple beams are designed to maximize the sampling density required to improve accuracy of global biomass estimates.

Forest growth, budding, and the dropping of leaves occur on fairly short timescales. Flying DESDynI instruments near simultaneously would provide the capability for fusing the InSAR and lidar data to provide a robust, validated measure of ecosystem structure. The lidar could also be used to measure the vertical change of disrupted surfaces from earthquakes, volcanoes, and landslides. The mission takes advantage of the precision and directness of the lidar with the global spatial coverage of the radar.

DESDynI would provide systematic global measurements to characterize processes, frequent measurements to understand temporal changes, and a 5-year duration to estimate long-term trends and determine subtle rates of deformation of the Earth's surface of less than 1 centimeter per year. Existing related spaceborne radar systems were not developed for scientific purposes; they provide only opportunistic science where measurements have been collected, and they cannot detect the long-period changes driving evolution of the Earth's near surface. Implementation of the radar- and lidar-enabled science as described in the decadal survey report will permit a better understanding of how our environment is changing and how to improve habitability of the Earth.

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LETTER

Who Really Failed New Orleans?

PAGES 350

I read with unusual interest the Forum "Earth Scientists and Public Policy: Have We Failed New Orleans?" in the 4 March issue of *Eos* (*89*(10), 2008). As an Earth scientist who lived in New Orleans during most of the early 1960s, I believe strongly that Earth scientists did not fail to recognize infrastructure problems. Further, they tried to communicate these problems and potential dangers to civic leaders in New Orleans and to government officials in Baton Rouge and Washington.

When I first moved to New Orleans in 1959, I studied existing topographic information carefully. After numerous conversations about the levee system with a cousin who worked for the U.S. Army Corps of Engineers, I concentrated my house search in the uptown section southwest of Tulane University, which was clearly the highest part of town. I bought a raised cottage (these are fairly common) after determining that the first floor above the ground-level basement was 2 feet higher than the top of the levee. I reasoned that even if a levee break did occur, my house would be slightly above flood level.

I pointed out to business leaders as well as some Washington politicians the risks of flooding due to having so many houses with ground floors below potential flood levels. Through my efforts and the efforts of others who felt the same way as I did, many people were made aware of the danger and a large federal grant was made to the city of New Orleans to help reduce the risks. Unfortunately, the mayor at that time spent the funds in a manner not intended or authorized by Congress—he built piers to dock gambling boats along the Mississippi, presumably with the goal of boosting downtown business and tourism.

The funds that were authorized to maintain the levees were instead spent on nonapproved projects that had nothing to do with the levee system. Earth scientists did not fail the city of New Orleans. A corrupt political system failed New Orleans!

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