



DEFORMATION, ECOSYSTEM STRUCTURE, AND DYNAMICS OF ICE (DESDynI) MISSION

Surface deformation is linked directly to earthquakes, volcanic eruptions, and landslides. Observations of surface deformation are used to forecast the likelihood of earthquakes as a function of location and to predict the places and times of volcanic eruptions and landslides. Advances in earthquake science leading to improved time-dependent probabilities would be facilitated by global observations of surface deformation and could result in increases in the health and safety of the public because of decreased exposure to tectonic hazards. Monitoring surface deformation is also important for improving the safety and efficiency of extraction of hydrocarbons, for managing groundwater resources, and, in the future, for providing information for managing CO₂ sequestration.

Radar and lidar measurements will probably help to understand responses of terrestrial biomass, which stores a large pool of carbon, to changing climate and land management. Benefits would include the potential for development of more effective land-use management, especially as climate-driven effects become more pronounced.

The poorly understood dynamic response of the ice sheets to climate change is one of the major sources of uncertainty in forecasts of global sea-level rise. DESDynI's InSAR measurements of the variations in ice-flow patterns and velocities provide important constraints on their dynamic response to climate change. Such knowledge will help to determine how fast society must adapt to sea-level changes and is crucial in planning the allocation of scarce resources.

Background: Earth's surface and vegetation cover change on a wide range of time scales. Measuring the changes globally from satellites would enable breakthrough science with important applications to society. Fluid extraction or injection into subterranean reservoirs results in deformation of Earth's surface. Monitoring the deformation from space provides information important for managing hydrocarbons, CO₂, and water resources. Natural hazards—earthquakes, volcanos, and landslides—cause thousands of deaths and the loss of billions of dollars each year. They leave a signature surface-deformation signal; measuring the deformation before and after the events leads to better risk management and understanding of the underlying processes. Climate change affects and is affected by changes in the carbon inventories of forests and other vegetation types. Changes in those land-cover inventories can be measured globally. Socioeconomic risks are related to the dynamics of the great polar ice sheets, which affect ocean circulation and the water cycle and drive sea-level rise and fall. Those processes are quantifiable globally, often uniquely, through space-based observations of changes of the surface and overlying biomass cover.

Science Objectives: Surface-deformation data provide the primary means of recording aseismic processes, provide constraints on interseismic strain accumulation released in large and damaging earthquakes, characterize the migration of large volumes of magma from deep within Earth to its surface (volcanos), and can be used to quantify the kinematics of active landslides. Earthquakes result from the accumulation of stress in Earth; because the crust behaves as an elastic material, the strain changes observable via InSAR can be used to determine stress changes and can lead to improved earthquake forecasts. Subterranean magma movement results in surface deformation. Observations of surface deformation via InSAR, particularly when combined with seismic observations, make volcanos among the natural hazards that can be predicted most reliably. Exploitation of hydrocarbon reservoirs also results in surface deformation, typically as the result of fluid withdrawal but also as the result of injection of fluids to stimulate production. It is often difficult to predict the trajectories of injected fluids, but observations of surface deformation can provide the needed constraints to improve the predictions. Observations of surface deformation also can be used to monitor the integrity of CO₂-sequestration wells.

The horizontal and vertical structure of ecosystems is a key feature that enables quantification of carbon storage, the effects of such disturbances as fire, and species habitats. Above-ground woody biomass and its associated below-ground biomass store a large pool of terrestrial carbon. Quantifying changes in the size of the pool, its horizontal distribution, and its vertical structure resulting from natural and human-induced perturbations, such as deforestation and fire, and the recovery processes is critical for measuring ecosystem change.

The dynamics of ice sheets are still poorly understood because their strength depends heavily on their temperature, their water content, conditions at their base, and even their history of deformation. Direct observations of how ice sheets deform in response to changes in temperature, precipitation, and so on, are crucial for understanding these important drivers of global sea-level change.

Mission and Payload: The DESDynI mission combines two sensors that together provide observations important for solid Earth (surface deformation), ecosystems (terrestrial vegetation structure), and climate (ice dynamics). The sensors are (1) an L-band synthetic aperture radar (SAR) system with multiple polarization

operated as a repeat-pass interferometer (InSAR), and (2) a multiple-beam lidar operating in the infrared (about 1,064 nm) with about 25-m spatial resolution and canopy-height accuracy of 1 m. The mission using InSAR to meet the science measurement objectives for surface deformation, ice sheet dynamics, and ecosystem structure has been studied extensively. The mission studied has a satellite in Sun-synchronous orbit at an altitude of 700-800 km in order to maximize available power from the solar arrays. An 8-day revisit frequency balances temporal decorrelation with required coverage. On-board GPS achieves centimeter-level orbit and baseline knowledge to improve calibration. The mission should have a 5-year lifetime to capture time-variable processes and achieve measurement accuracy.

For ecosystem structure, L-Band InSAR measurements allow estimating forest height with meters accuracy; interferometry allows estimation of three-dimensional forest structure. The sensitivity of backscatter measurements at different wave polarizations to woody components and their density makes radar sensors suitable for direct measurements of live above-ground woody biomass (carbon stock) and structural attributes such as volume and basal area. The multibeam laser altimeter (lidar) system would accurately measure the distance between the canopy top and bottom elevation, the vertical distribution of intercepted surfaces, and the size distribution of vegetation components within the vertical distribution. Multiple beams measure different size components of vegetation. Although this measurement is the most direct estimate of the height and the vertical structure of forests, the lidar measurement samples Earth's surface at discrete points, rather than imaging the entire surface. DESDynI combines the two approaches, taking advantage of the precision and directness of the lidar to calibrate and validate the polarimetric SAR and InSAR measurements, especially in ecosystem types where field campaigns have not occurred.

The radar and lidar measurements do not need to be made simultaneously but could be separated by up to a few weeks because ecosystem structure typically does not evolve substantially on shorter time scales. Whether both instruments are flown on the same platform or separate platforms should be determined by a more thorough study. For example, it might be possible to upgrade the ICESat-II mission to include multibeam performance to meet the ecosystem requirements as long as the two missions are launched within the same time frame and take measurements within a few weeks of each other.

The SAR instrument consists of an L-band (1.2-GHz) radar that can be operated in several modes: single or dual-polarization strip-mapping mode, full-polarization strip-mapping mode, and single or dual-polarization ScanSAR mode with extended swath. The L-band wavelength, as well as the short repeat period, minimizes temporal decorrelation in regions of appreciable ground cover. Because the orbital geometry is tightly controlled, data acquired in all modes will provide excellent InSAR capability. Two subbands separated by 70 MHz allow correction of ionospheric effects. The viewable swath width must be larger than 340 km to obtain complete global access. Other characteristics include ground resolution better than 35 m to characterize fault geometries, noise equivalent σ° less than -24 dB to map radar-dark regions, electronic-beam steering to minimize spacecraft interactions for acquisition and allow ScanSAR operation, and a data rate of at least 140 Mbps. Multiple polarization is required for the canopy-density profiles needed for ecosystem structure. As noted above, the lidar in DESDynI is a multibeam laser ranger operating in the IR.

Cost: About \$700 million.

Schedule: The technology readiness of all components is consistent with a new start now. Past studies and proposals to NASA show that all technologies required for both the InSAR and the lidar have been demonstrated in space by U.S. or international satellites.

Further Discussion: See in Chapter 8 the section “Mission to Monitor Deformation of Earth’s Surface,” in Chapter 9 the section “Climate Mission 3: Ice Dynamics,” and in Chapter 7 the section “Information Requirements for Understanding and Managing Ecosystems.”

Related Responses to Committee’s RFI: 44, 57, 72, 73, and 83.

Related Reading:

NASA (National Aeronautics and Space Administration). 2002. *Living on a Restless Planet*. Solid Earth Science Working Group Report. Jet Propulsion Laboratory, Pasadena, Calif. Available at <http://solidearth.jpl.nasa.gov/seswg.html>.

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NRC. 2003. *Living on an Active Earth: Perspectives on Earthquake Science*. The National Academies Press, Washington, D.C.

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