DESDynl – Deformation, Ecosystem Structure and Dynamics of Ice

Mission Concept, Possible Roles in US Hazard Monitoring and Mitigation, and Status

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Briefing to the NSTC Subcommittee on Disaster Reduction
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DESDynI Science

Recommended by the NRC Decadal Survey for near-term launch to address important scientific questions of high societal impact:

- What drives the changes in ice masses and how does it relate to the climate?
- How are Earth’s carbon cycle and ecosystems changing, and what are the consequences?
- How do we manage the changing landscape caused by the massive release of energy of earthquakes and volcanoes?

Planned by NASA as one of the following 4 Decadal Survey TIER 1 Missions

- SMAP
- ICESat-II
- DESDynI
- CLARREO

Ice sheets and sea level

- Will there be catastrophic collapse of the major ice sheets, including Greenland and West Antarctic and, if so, how rapidly will this occur?
- What will be the time patterns of sea level rise as a result?

Changes in ecosystem structure and biomass

- How does climate change affect the carbon cycle?
- How does land use affect the carbon cycle and biodiversity?
- What are the effects of disturbance on productivity, carbon, and other ecosystem functions and services?
- What are the management opportunities for minimizing disruption in the carbon cycle?

Extreme events, including earthquakes and volcanic eruptions

- Are major fault systems nearing release of stress via strong earthquakes?
- Can we predict the future eruptions of volcanoes?
Sources for Science Objectives

Fourth component of EarthScope

Involvement:
NSF, NASA, USGS, Universities

Highest priority of NASA’s Solid Earth Science Working Group
Supported in NRC Review

Recommended for the Global Earthquake Satellite System

Department of Defense Applications

Engaging hundreds of scientists and user communities in multiple disciplines

…as captured in the NASA Science Plan

Howard Zebker (Chair) Stanford
Involvement:
NASA, NSF, USGS, Universities (63)
A Call for Hazards Monitoring

Surface deformation and change are recognized as key measurements for hazard monitoring and mitigation in numerous reports beyond the NRC Decadal Survey

- In “Achieving and Sustaining Earth Observations: A Preliminary Plan Based on a Strategic Assessment by the US Group on Earth Observations” (September 2010):
  
  NASA should launch the radar portion of the NRC Decadal Survey mission Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI) mission…
  The L-Band Interferometric Synthetic Aperture Radar (InSAR) will provide surface deformation measurements.

- Similar recommendations have been made for over 15 years
  - Open letter to NASA Earth Science Administrator from Solid Earth Community (1994)
  - Subcommittee on Disaster Reduction Working Group Reports (2008)

The US cannot continue to rely on foreign or overtaxed intelligence assets to meet the needs of the science and hazard response communities
DESDynI Science to Implementation

January 2011 Concept

- **Ecosystem Structure**
  - Biomass, Vegetation Structure, Effects of changing climate on habitats and CO₂, disturbance

- **Cryosphere**
  - Ice velocity, thickness
  - Response of ice sheets to climate change & sea level rise

- **Solid Earth**
  - Surface Deformation
  - Geo-Hazards
  - Water Resource Management

**L-band Polarimetric SAR**
- 91-day repeat
- ~370 km orbit
- 25 m spot
- 5 beams

**Multibeam Profiling LIDAR**
- 13 day repeat
- ~600 km orbit
- 250-500 m orbit control
- 220 km swath
- Full resolution over swath
- 5,20+5,40,80 MHz modes
- SP, DP, QQP, QP modes

Two spacecraft not at same scale
Interferometric SAR Technique

Through careful control of the orbit, it is possible to combine two complex images acquired from space to measure millimeter scale motions of the ground.

Desired InSAR Characteristics
- Rapid repeat and frequent revisit
- Tight orbit control
- Long radar wavelength
- Wide swath
2003 Mw=6.6 Bam Earthquake view with InSAR

Surface Rupture from EnviSAT

Model Deformation

Optical Data (no evidence of change)
2003 Mw=6.6 Bam Earthquake view with InSAR

Surface Motion from EnviSAT InSAR (Fialko et al., 2005)

Vector deformation images from space show limited surface disruption, indicating low stress in upper crust
NASA’s UAVSAR
First Airborne Measurement of an Earthquake

- **Response**: Maps regions of ground disturbance & destruction for use in earthquake response
- **Forecasting**: Determines regions of strain build-up near and along faults for improved hazard forecasts
UAVSAR Central California Subsidence

Interferogram showing subsidence (ground sinking) due to oil pumping

Legend
-6cm 0 +6cm

2010-09: Central California
Localized deformation along levee could be indicative of some structural weakness.

Displacements measured from June 16 to September 9, 2009.
Oil Detection and Characterization
In Both Open Water and Coastal Wetlands

*Radar images the surface in all light-weather conditions – through clouds, day or night. UAVSAR is able to detect oil in the main slick on open water and coastal waterways, and detect impacted vegetation in the coastal marshlands.*

**Gulf of Mexico:**

The oil stands out clearly in the UAVSAR PolSAR radar image, showing variations in the main slick depending upon varying oil characteristics.

This capability could be used for targeting response operations to highly oiled areas.

Reference: B. Minchew, C.E. Jones, B. Holt (Caltech/JPL)

**Barataria Bay, Louisiana:**

Oil on water shows as dark areas in the radar image.

Studies of oiled vegetation in this area showed that UAVSAR can detect oil on water and on vegetation in coastal marshlands.

Reference: E. Ramsey, A. Rangoonwala, Y. Suzuoki (USGS), C.E. Jones (Caltech/JPL)
Large amounts of oil moved far into Barataria Bay in SE Louisiana on 16-17 June 2010, with oil remaining in the area until after the UAVSAR over-flight.

Weathered oil in the interior of Barataria Bay shows a significantly higher entropy than oil around the rig site or in the Gulf of Mexico approaching the Louisiana shoreline.
DESDynI Mission
A source of global data for earthquake research and response

• Fills a major observational gap in developing the big picture on earthquake likelihood
  – US annualized losses from earthquakes are $5.3B/yr
  – DESDynI will deliver data to inform and improve hazard maps to finer resolution in space and time

Average 4-day response for earthquakes indicating location and likelihood of M>5.5 aftershocks.

Needed inputs to modeling, forecasting and response.
SAR Provides Scientific Insight That Will Save Lives and Property

**InSAR Data and Analysis**

![InSAR Data and Analysis](image)

- Fundamental Physics and Discovery of Earth Surface Change

**Modeling and Application**

![Modeling and Application](image)

- High Resolution Earthquake Hazard Information (Stress Map)

**Planning and Preparation**

![Planning and Preparation](image)

- Targeted retrofitting in high-risk areas
- Rapid response and recovery
- Early warning

**InSAR Data and Analysis**

- InSAR Data and Analysis
- Modeling and Application
- Planning and Preparation
ARIA-EQ: Advanced Rapid Imaging and Analysis for Earthquakes

Rapid Response Proof-of-Concept
A controlled experiment to map building damage with satellite radar

From space we can now detect building damage anywhere, anytime of day, regardless of clouds.

Google Earth image of Pasadena study area

ARIA-EQ: Using DESDynI for Rapid Response

Colorado Blvd

Del Mar Blvd
Research and Response

Understanding Earthquakes

- Detecting and interpreting tectonic strain
- Understanding California's system of faults

Rapid Assessment

Mw 7.2 El Mayor-Cucapah Earthquake
Baja California - April 4, 2010
# DESDynI Requirement Summary from MCR

<table>
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<tr>
<th>Science Objectives</th>
<th>Measurement Requirements</th>
<th>Stressing Instrument Capabilities</th>
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<tr>
<td><strong>Ecosystem Structure</strong></td>
<td>• Canopy height and structure metrics accurate to 1 m (low slope) at 1000 m resolution in 2 yrs</td>
<td>• 5-beam profiling lidar operated at near nadir incidence, 25 m profile resolution</td>
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<td>• Biomass at 100-200 m resolution in low biomass</td>
<td>• Lidar 91-day repeat orbit</td>
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<td>• High fidelity forest change maps, annually</td>
<td>• Quad-pol L-band radar operating in 30-44° incidence angles at 10 m res, seasonally</td>
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<td>• Global biomass/carbon</td>
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<tr>
<td>• Biomass disturbance</td>
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<td>• Biomass loss due to land use change</td>
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<tr>
<td>• Habitat and biodiversity</td>
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<td><strong>Dynamics of Ice</strong></td>
<td>• 2-D velocity accurate to 1 m/yr at 100-500 m res over ice sheets and glaciers, 3 yrs</td>
<td>• 5-beam profiling lidar operated near nadir, 25 m profile res</td>
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<tr>
<td>• Ice sheet dynamics</td>
<td>• DEM topography accurate to 1 m at 1 km res over ice sheets and glaciers</td>
<td>• Lidar 91-day repeat orbit</td>
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<tr>
<td>• Glacier dynamics</td>
<td>• dh/dt to 1 m/yr at 2500 m res</td>
<td>• L-band co-pol radar operating in 13 day repeat period orbit, global accessibility, at 10 m res,</td>
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<tr>
<td>• Sea ice dynamics</td>
<td>• Elevation precise to 3 cm at 25 m profile res over sea ice</td>
<td>continuously over mission, over all interesting science targets</td>
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<tr>
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<td>• Sea-ice velocity to 100-m/day at 5 km res, Arctic and Antarctic</td>
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<tr>
<td><strong>Deformation</strong></td>
<td>• 2-D velocity time series accurate to 1-5 mm/yr at 10-1000 m res over all active areas, 3 yrs</td>
<td>• L-band co-pol radar, 13 day repeat period, global accessibility</td>
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<tr>
<td>• Tectonic processes</td>
<td>• Weekly or shorter target sampling</td>
<td>• Weekly target sampling at equator, better at higher latitudes</td>
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<td>• Magmatic processes</td>
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<td>• 10 m resolution</td>
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<tr>
<td>• Sequestration, landslides, aquifer change</td>
<td></td>
<td>• All continuously over mission, over all interesting science targets</td>
</tr>
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International SAR Missions

- SeaSAT
- SIR-A
- SIR-B
- Challenger
- SIR-C/
- X-SAR
- SRTM
- Earth
- JERS-1
- RADARSAT-1
- Envisat-1
- ERS-1
- ERS-2
- ALOS
- RADARSAT-2
- TerraSAR-X
- TanDEM-X
- Cosmo-Skymed

Launch: 1980 - 2010
Orbit: 1985 - 2015
InSAR?
Community Starved for Data

• Volume of international SAR data is highly limited
• US/NASA was world’s largest consumer of L-band SAR/InSAR data from ALOS
• NASA instituted use of TDRSS in April 2010 to double capacity of mission, with over 100,000 scenes per year ingested for scientific use
• DESDynI class mission would provide on order of 1 million scenes per year to satisfy known global science requirements.
• International SARs except Envisat are all fully or quasi-commercial
  – Cost per scene of $3-6K
  – Low-cost science data is limited to 50 scenes per investigator through proposal process
  – Not possible to buy DESDynI science from international providers at these costs, even if the data were available and suitable
• DESDynI class mission could help satisfy the need for observations over a broad range of hazards: geohazards, flooding, oil spills, damage assessment, environmental monitoring, monitoring of infrastructure/lifelines, and others
Outlook for DESDynI

• Successful Mission Concept Review in January 2011
• President’s FY12 budget proposal reset the go-forward plan for DESDynI
  – Lidar mission to be contributed, not funded by NASA
  – Radar mission to be implemented more affordably
• NASA is currently exploring options for reducing cost
  – Reducing number and scope of science requirements levied on DESDynI
    + Combine DESDynI with other satellites to approach DESDynI requirements
  – Find international partners interested in the science and technology
  – Find domestic partners that would increase utility and value of DESDynI data
Summary

- DESDynI would provide exciting scientific returns in three distinct science disciplines
  - Final scope of mission still to be defined
  - Depends on strength of community advocacy and partnership contributions

- DESDynI would provide direct benefits to society as its measurements are used to help forecast sea level rise and the likelihood of earthquakes or volcanic eruptions and to improve forest inventories and carbon monitoring
  - Benefits of regular repeated measurements also apply to hazard monitoring and mitigation

- DESDynI measurements would be unique and available to the world for scientific and other uses
  - L-band full-resolution, full-swath, fast repeat capability would revolutionize our ability to characterize natural hazards, quantify ice dynamics, and monitor Earth’s changing terrestrial carbon stocks
  - Accuracy/resolution/coverage would be major improvement for US scientists

- Science community and technology are ready to go