DESDynI
A NASA Mission for Ecosystems, Solid Earth and Cryosphere Science

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PollnSAR 2008

http://desdyni.jpl.nasa.gov
### Objectives

**Determine the likelihood of earthquakes, volcanic eruptions, and landslides**

US annualized losses from earthquakes are $4.4B/yr yet current hazard maps have an outlook of 30–50 years over hundreds of square kilometers.

**Characterize the effects of changing climate and land use on species habitats and carbon budget**

The rate of increase of atmospheric CO₂ over the past century is unprecedented, at least during the past 20,000 years. The structure of ecosystems is a key feature that enables quantification of carbon storage.

**Predict the response of ice sheets to climate change and impact on sea level**

Ice sheets and glaciers are exhibiting dramatic changes that are of significant concern for science and international policy. These indicators of climate remain one of the most under-sampled domains in the system.

### Operational Concept

**Approach**

- Repeat Pass InSAR
- Finite Baseline InSAR and Polarimetric SAR
- Multibeam LIDAR

**Targets**

- Solid Earth
- Ecosystem Structure
- Cryosphere

### Mission Timeline

- **Pre-formulation/risk reduction** 2008
- **Concept development** 2009
- **Preliminary design** 2010
- **Design to Launch** 2010–2015
- **Launch** 2015
- **Operations** 2015–2020
Recommended by the NRC Decadal Survey for near-term launch to address important scientific questions of high societal impact:

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

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

- SMAP
- ICESat-II
- DESDynI
- CLARREO

Extreme events, including earthquakes and volcanic eruptions

- Are major fault systems nearing release of stress via strong earthquakes
- Eruptive state of volcanoes?

Shifts in ecosystem structure and function in response to climate change

- How will coastal and ocean ecosystems respond to changes in physical forcing, particularly those subject to intense human harvesting?
- How will the boreal forest shift as temperature and precipitation change at high latitudes?
- What will be the impacts on animal migration patterns and invasive species?

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?
DESDynI Mission Sciences
- Deformation of Solid Earth for improving forecasts of seismic and volcanic events
- Ecosystem Structure for improving carbon budget and carbon cycle modeling
- Dynamics of Ice for improving understanding of changes in ice masses and climate

Instrumentation
- Multi-beam Profiling Lidar
- Fully-polarimetric Mult-mode L-band Radar
- GPS receivers for precision orbit determination and reconstructions
Launch date: Sep 2015 (assume Phase A starts Oct 2010)
Mission lifetime: 5 years
Target body: Earth

Trajectory/Orbital details for Options:

- **Option 1 (Radar+Lidar Co-flyer):** Near-circular 600 km sun synchronous 6 am to 6 pm; orbit is 8-12-day repeat track, near-circular, frozen (i.e., periapse stays near north pole), sun-synchronous

- **Option 2 (Radar-only and Lidar-only separate platforms):**
  - Radar-only platform: Near-circular 760 km sun synchronous 6 am to 6 pm; orbit is 8-day repeat track, near-circular, frozen (i.e., periapse stays near north pole), sun-synchronous
  - Lidar-only platform: Near-circular 400 km sun synchronous 6 am to 6 pm; orbit is 90-day repeat track, near-circular, frozen (i.e., periapse stays near north pole), sun-synchronous

- **Option 3 (Tandem Radar):** Use Radar-only platform in Option 2 as the first platform, replicate it as the second platform slaved to first

Reliability/redundancy requirements: Lidar-5 years. SAR-5 years. GPS-90% probability to operate for 5 years. Partial redundancy; EEE parts Level 2 with Class B+ parts

Data latency: space-to-ground ≈ hours; to users ≈ < 8 days

Calibration requirements: LIDAR (see backup). SAR- earth based. GPS-None at this time.

De-orbit: No constraints at this time

Launch vehicle constraints: Mass and volume
The Decadal Survey compromise altitude of 600km is appropriate considering the two primary trades:

- **Delta-V**: costs rise sharply for DESDynI as altitude decreases.
- **LIDAR**: Telescope aperture complexity increases as altitude increases, with a large jump in near 600 km due to non-COTS availability.
- This compromise should also be viewed in the context of the challenge of launching and operating 2 S/C that can be optimized individually.

**Delta-V/yr for Orbit Maintenance**

During the DESDynI Mission lifetime, the sun will transition from solar max to solar min.

**Lidar Pulse Power and Aperture**

With each decrease of 50km, yearly drag-makeup delta-v doubles.

600km Orbit is right on the cusp of COTS to non-COTS telescope hardware.
Observation Scenarios

For the SAR and Lidar, data taking will be over land and ice:

- 3-month on-orbit checkout, verification and validation over select targets/areas
- 6-month global baseline data acquisition
- Continuous observations over focused regions
- Provision for target-of-opportunity/disaster-response observations
- Provision for none-core discipline observations (e.g. hydrology and oceanography applications)

SAR orbital data taking in dual-pol over 15% and quad-pol for 10%:

- Yaw maneuvers for left-right observations of the same area

Lidar orbital data taking over 30% plus over-ocean calibration:

- Twice/day 20min deep ocean calibration with conical scan (10deg around nadir)

GPS data taking over 100% of the orbit excepted maneuvering
**Configuration and Concept**

- Radar look direction is 30° off-nadir (30° off z)
- Radar FOV is ±15° off axis

**Features**
- L-Band SAR with 15m mesh reflector and phased array feed with electronically steering beams
- Instrument can operate in single-, dual-, quad-pol modes
- Array feed consists of 34 T/R elements in elevation by one in azimuth
- All 34 elements transmit at the same time; 2-3 elements receive in quick switching

**Technology**
- Key required advanced technology investments have already been made
  - L-band TR modules, antenna designs, trade studies, and modeling and simulation under ESTO, UAVSAR system for quad-pol InSAR from aircraft, and digital assemblies through MSL
  - Smaller size reflector (<12m) flown; thermal modeling and pointing under investigation
  - New wide-swath quad-pol SAR technique to be simulated and verified

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reflector Size (m, dia)</td>
<td>15</td>
</tr>
<tr>
<td>Bandwidth (Center) (MHz)</td>
<td>25 (1250)</td>
</tr>
<tr>
<td>Peak Power/Average (W)</td>
<td>1724/460</td>
</tr>
<tr>
<td>Look Angle (Deg)</td>
<td>20 – 40</td>
</tr>
<tr>
<td>PRF Dual/Quad (Hz)</td>
<td>1300/2600</td>
</tr>
<tr>
<td>Max Swath Width (Km)</td>
<td>350</td>
</tr>
<tr>
<td>Res. (1 look) (m x m)</td>
<td>11 x 8</td>
</tr>
<tr>
<td>NE&lt;sub&gt;e0&lt;/sub&gt; (dB)</td>
<td>-35</td>
</tr>
<tr>
<td>Total Ambiguities (dB)</td>
<td>-20</td>
</tr>
<tr>
<td>Data Rate: Peak/Orbit Average (Gbps)</td>
<td>2.1/0.48</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>521</td>
</tr>
</tbody>
</table>
Features of the Instrument Concept

Nadir-pointed Multi-Beam Lidar (1064 nm)
- 5-beams spaced nominally 5 km across-track
- 25 m laser footprint, 30 m along track spacing
- Multi-Beam Lidar operates as a vegetation structure sampler

Expected Multi-Beam Lidar Lifetime
- 6+ years
- Laser tested to 5B shots.
- Diodes tested to equivalent of 3 years of operations (so far) with <1% degradation.

Performance:
- Range Resolution: 3 cm (bare ground), 1 m (vegetation)
- Geolocation accuracy: 10 m horiz., <0.1 m vertical

Technology Development Needs
Laser transmitter is currently at TRL 6:
- 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 FY08 has verified the Multi-Beam Lidar performance in a relevant environment (vibration, thermal vacuum, etc.) to TRL 6.
Antenna Trade Studies

- Phased Array vs. Reflector + Phased Array Feed

- Pros and cons to both designs
  - Stow volume?
  - Roll versus yaw maneuvers

- Reflector
  - Lighter
  - Lower cost

- Planar Array
  - Greater range of beam steering to accommodate off-pointing of the lidar
  - Greater flexibility in operation
  - More graceful degradation of the TR modules

DESDynl team have elected to go with reflector option
- Very low mass/unit area
- Reflector and deployment mechanism have high heritage (TRL 9) from GEO comm platforms
- Phased array feed allows flexibility in the elevation illumination pattern (but not in azimuth)
- Fixed phased array feed is a simpler engineering problem than a deployable phased array
- Improved SNR (or lower Tx power)
- Possibility of Adaptive Echo Tracking on Receive (SweepSAR?)
• Modified Quad-pol mode has data acquired in circular transmit, linear receive (from a suggestion by K. Raney):

\[
\begin{pmatrix}
M_{RH} & M_{LH} \\
M_{RV} & M_{LV}
\end{pmatrix} =
\begin{pmatrix}
S_{hh} - jS_{hv} & S_{hh} + jS_{hv} \\
S_{hv} - jS_{vv} & S_{hv} + jS_{vv}
\end{pmatrix}
\]

• Advantage is that receiver gain does not have to be alternated
• Next transform to (H, V) basis (Freeman-Raney IGARSS 2008 paper):

\[
\begin{pmatrix}
M_{HH} & M_{VH} \\
M_{HV} & M_{VV}
\end{pmatrix} =
\begin{pmatrix}
S_{hh} - jS_{hv} & S_{hh} + jS_{hv} \\
S_{hv} - jS_{vv} & S_{hv} + jS_{vv}
\end{pmatrix} \frac{1}{2} \begin{pmatrix} 1 & j \\ 1 & -j \end{pmatrix}
\]

• Net result is that all range ambiguities have same polarization as desired returns
• In particular, in HV measurements, range ambiguities are HV-polarized (similar for VH)
• Improvement over linear quad-pol operation, for which odd-numbered range ambiguities in the HV channel are VV-polarized (which limits performance at higher inc. angles)
• Modified quad-pol is currently baselined for DESDynI
Ionosphere Problem

- Model predictions of FR based on TEC, magnetic field

\[ \Omega = \frac{K}{f^2} \int_0^h NB \cos \psi \sec \theta_0 \, dh \]

Mean Faraday Rotation at L-Band, April, GMT = 12:00

Moderate Sunspot activity
R=20

High Sunspot activity
R=160

- Proposed pre-rotation of transmitted wave to adjust for expected FR
- Note \( \Omega = 0 \) crossing at Equator

**DESDynl may have to deal with higher sunspot activity if we launch early**
With interferometric observations at two slightly different wavelengths, solve for two unknowns:

- True surface displacement (desired quantity) $\delta_{\text{surface}}$
- Differential ionosphere TEC $\Delta T$
- Baseline for DESDynI single-pol modes

\[
\Delta \phi_1 = 4\pi \left( \frac{\delta_{\text{surface}}}{\lambda_1} - \frac{a}{c^2} \lambda_1 \Delta T \right)
\]

\[
\Delta \phi_2 = 4\pi \left( \frac{\delta_{\text{surface}}}{\lambda_2} - \frac{a}{c^2} \lambda_2 \Delta T \right)
\]

\[
\delta_{\text{surface}} = \frac{\lambda_1 \Delta \phi_2 - \lambda_2 \Delta \phi_1}{4\pi \left( \frac{\lambda_1}{\lambda_2} - \frac{\lambda_2}{\lambda_1} \right)}
\]

\[
\Delta T = \frac{\lambda_2 \Delta \phi_2 - \lambda_1 \Delta \phi_1}{4\pi \frac{a}{c^2} \left( \lambda_2^2 - \lambda_1^2 \right)}
\]
Polarimetric Calibration:

Ω, δ's are small and cross-talk is symmetric

- For small Ω, δ’s system model can be expressed as:
\[
\begin{pmatrix}
M_{hh} & M_{vh} \\
M_{hv} & M_{vv}
\end{pmatrix} = A(r, \theta) e^{j\Phi} \begin{pmatrix}
1 & (\Omega + \delta_2)/f_1 \\
\delta_1 - \Omega f_1 & 1
\end{pmatrix} \begin{pmatrix}
S_{hh} & S_{vh} \\
0 & f_1 S_{hv} S_{vv} 0
\end{pmatrix} \begin{pmatrix}
1 & 1 \\
(\delta_4 - \Omega)/f_1 & f_2/f_1
\end{pmatrix} + \begin{pmatrix}
N_{hh} & N_{vh} \\
N_{hv} & N_{vv}
\end{pmatrix}
\]

- which is identical in form to Quegan’s method, an application of which should yield:
\[
F = f_1/f_2; \quad \delta_1 = \delta_1 - \Omega f_1; \quad \delta_2 = (\Omega + \delta_2)/f_1
\]
\[
\delta_3 = \delta_3 + \Omega f_2; \quad \delta_4 = (\delta_4 - \Omega)/f_1
\]

- For radar antennas whose cross-talk is symmetric on transmit and receive*, i.e.
\[
\delta_1 = \delta_3 \text{ and } \delta_2 = \delta_4
\]

- Thus
\[
F = f_1/f_2; \quad \delta_1 = \delta_1 - \Omega f_1; \quad \delta_2 = (\Omega + \delta_2)/f_1
\]
\[
\delta_3 = \delta_3 + \Omega f_2; \quad \delta_4 = (\delta_4 - \Omega)/f_2
\]
\[
f_1 = \sqrt{2 \frac{(\delta_3 - \delta_4)}{(\delta_2 - \delta_4/F)} \left( \frac{F}{F+1} \right)}; \quad \Omega = \frac{f_1}{2} (\delta_2 - \delta_4/F); \quad f_2 = f_1/F;
\]
\[
\delta_1 = \left[ (\delta_1 + \delta_3) - \Omega (f_2 - f_1) \right]/2; \quad \delta_2 = f_1 (\delta_2 + \delta_4/F)/2
\]

- Only restriction is that Ω ≠ 0 and f_2 ≠ -f_1

*Design constraint for DESDynI radar
Adaptive Echo-Tracking (SweepSAR?)

- Reflector + Phased Array feed option allows rapid elevation beam scanning on receive (SweepSAR)
- Idea is to sub-illuminate on transmit which gives a wide swath
- Then use a smaller number of T/R modules on receive to receive echoes from more of the reflector
- Increases gain on receive by using more of the available reflector area
- Achieve wide swath by shifting the locus of the T/R modules used to receive signals
- Shifting should be done so that the receive antenna beam sweeps out to track location of the pulse echo return
- This shifting of the T/R modules used to form the receive beam can be done cheaply in analog
- Similar to an STC in nature - requires rapid switching
- May require use of two receivers to handle overlap between pulse echoes
Adaptive Echo-Tracking (SweepSAR?)

- Concept Illustration

Transmit beam covers the entire swath - Beam (1)

Receive Sequence - Beams (2), (3), (4)

- High-gain receive beam is ‘swept’ across the swath to track the location of the pulse echo similar to whiskbroom concept in E/O
<table>
<thead>
<tr>
<th>Parameter/System</th>
<th>Conventional SAR</th>
<th>Offset Fed SweepSAR</th>
<th>Center Fed SweepSAR</th>
<th>Center Fed SweepSAR</th>
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<tbody>
<tr>
<td></td>
<td>SCANSAR</td>
<td>Quad Pol</td>
<td>Wide Swath</td>
<td>Quad Pol</td>
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<tr>
<td>Altitude</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>600</td>
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<tr>
<td>Peak Transmit Power</td>
<td>2000</td>
<td>2000</td>
<td>2800</td>
<td>2800</td>
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<tr>
<td>Avg Radiated Power</td>
<td>550</td>
<td>452</td>
<td>75</td>
<td>150</td>
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<tr>
<td>Antenna Boresight</td>
<td>35</td>
<td>35</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>PRF Processing Bandwidth</td>
<td>1281</td>
<td>2408</td>
<td>1384</td>
<td>2663</td>
</tr>
<tr>
<td>Number of Looks</td>
<td>14</td>
<td>100</td>
<td>110</td>
<td>100</td>
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<tr>
<td>Swath</td>
<td>340</td>
<td>60</td>
<td>178</td>
<td>160</td>
</tr>
<tr>
<td>Field of Regard</td>
<td>340</td>
<td>340</td>
<td>178</td>
<td>160</td>
</tr>
<tr>
<td>Data Rate</td>
<td>332</td>
<td>424</td>
<td>653</td>
<td>1493</td>
</tr>
<tr>
<td>Bits/(Looks*Swath)</td>
<td>69.7</td>
<td>70.7</td>
<td>33.4</td>
<td>93.3</td>
</tr>
</tbody>
</table>

System resolution 100 m, Bandwidth 25 MHz
Center Fed Dual Polarization SweepSAR - 600 km

300 Kilometer Swath

Number of Looks

Sigma Zero

Total Ambiguities

5.9 Kilometer Data Gap

Noise Equivalent Sigma Zero

Distance From Nadir in Kilometers
PolInSAR 2009
Center Fed Quad Polarization
SweepSAR – 600 km

Sigma Zero
8 Kilometer Gap
4 Kilometer Gap
Number of Looks
Total Ambiguities
Noise Equivalent Sigma Zero
310 Kilometer Swath

Distance From Nadir in Kilometers

0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0

200.0 250.0 300.0 350.0 400.0 450.0 500.0 550.0 600.0
Mission Sciences
- Deformation of Solid Earth for improving forecasts of seismic and volcanic events
- Ecosystem structure estimation for global above ground biomass & annual change derivation important for carbon cycle & forest management
- Dynamics of ice for improving understanding of changes in ice masses and climate

Mission and Instrumentation
- Dual Radar spacecraft in formation flying (single pass Pol-InSAR for 3D structure & deformation)
- Optical terminal for high rate/volume data handling

Study Highlights/Challenges (complete by Sept 2009)
- Integration observation strategies among science disciplines
- Selection of optimal formation flying orbits
- Selection/design of dual radar operation technique, monostatic and/or bistatic operations
- Assessment of alternate SAR techniques (ScanSAR vs. digital beamforming)
- Assessment of reflector with arrayed feed antenna or planar active phased array
- Assessment of cost and possible workshare
- Exploration of NASA/JPL collaboration
Summary

The DESDynI Mission will provide outstanding science return using innovative techniques.

Partnership between JPL and DLR is proving to be one of the most fruitful and stimulating I have ever been involved in.

DESDynI team are currently studying how to best leverage expected significant increase in funding from the economic stimulus package.