A Dual-Frequency Spaceborne SAR Mission Concept

P. Rosen, Y. Kim, H. Eisen, S. Shaffer, L. Veilleux, S. Hensley
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, CA USA

M. Chakraborty, T. Misra, R. Satish¹, D. Putrevu, R. Bhan
Space Applications Centre, ISRO, Ahmedabad 380015, India
¹ISRO Satellite Centre, ISRO, Bangalore 560017, India

July 24, 2013
A NASA-ISRO SAR Mission Concept

- The National Aeronautics and Space Administration (NASA) and the Indian Space Research Organization (ISRO) have been engaged in technical and programmatic exchanges on a possible joint SAR mission since December 2011.

- A new SAR mission concept has emerged that addresses a broad range of science and applications objectives assigned in the 2006 US Decadal Survey to the proposed Tier 1 DESDynI Mission, as well as ISRO’s long term observing plans.

- The mission is now conceived as a partnership with many exciting “firsts”:
  - Dual-Frequency (L- and S-band) free-flyer
  - Unprecedented coverage, resolution, and sampling in time
  - New SAR technology to realize wide swath
  - Bilateral agreement on open data policy
  - Major mission-level, balanced, NASA-ISRO partnership
Mission Science Definition Team

- NASA selected a Science Definition Team (SDT) in Spring 2012 to help craft a scientifically compelling, affordable SAR mission

Project Scientist – Paul Rosen, JPL

NASA SDT Leads

| Ian Joughin, Applied Physics Lab, U Washington (Dynamics of Ice) |
| Ralph Dubayah, U Maryland (Ecosystems) |
| Bradford H. Hager, MIT (Deformation/Solid Earth) |

ISRO Science Contact – Manab Chakraborty, ISRO Space Applications Center

NASA SDT Members

| Gerald Bawden, USGS | Matt Pritchard, Cornell University |
| Kurt Feigl, U Wisconsin | Eric Rignot, UC Irvine |
| Ben Holt, JPL | Sassan Saatchi, JPL |
| Josef Kellindorfer, Woods Hole Research Center | Mark Simons, Caltech |
| Ronald Kwok, JPL | Paul Siqueira, U Massachusetts |
| Zhong Lu, USGS | Howard Zebker, Stanford University |
| Franz Meyer, U Alaska, Fairbanks | |
Science Inspired by the “Decadal Survey”

The 2006 US NRC Decadal Survey recommended the DESDynI Mission 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?
- Understand the physics of earthquakes and volcanoes sufficiently to apply to mitigation of natural hazards

The Mission Science Definition Team (SDT), in partnership with ISRO scientists, has validated the continuing importance of these science objectives.

The NASA/ISRO SDT has developed a set of integrated requirements to address these and other important questions.

Cryosphere, 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 resulting time patterns of sea level rise?
- How are alpine, e.g. Himalayan, glaciers, changing in relation to climate?

Changes in ecosystems and biomass
- How do changing climate and land use in forests, wetlands, and agricultural regions affect the carbon cycle and species habitats?
- What are the effects of disturbance on ecosystem functions and services?

Solid Earth - Extreme events
- Are major fault systems nearing release of stress via strong earthquakes?
- Can we predict the future eruptions of volcanoes?
- What are optimal remote sensing strategies to respond to earthquakes, volcanoes, floods, fires, and other such disasters?

Coastal Processes
- What is the state of important mangroves of India?
- How are Indian coastlines changing?
- What is the shallow bathymetry around India?
- What is the variation of winds in India’s coastal waters?
Draft NASA Level 1 Science Requirements

- For a minimum of 3 years:
  - Measure displacements over Earth’s land and ice covered surfaces with an accuracy of 20 mm with an average sampling capability of 6 days at hectare scale.
  - Measure sea ice displacements at 100 m/day accuracy on a 5 km grid every 3-days
  - Measure global woody aboveground biomass below 80 Mg/ha at 20 Mg/ha accuracy, and disturbance/recovery, at hectare scale, annually.
  - Acquire targeted data sets to characterize wetlands inundation, agricultural systems, aquifers, hydrocarbon reservoirs, permafrost, and coastal winds
  - In the event of a major natural or anthropogenic disaster anywhere in the world, data shall be made available for rapid response
# NASA-ISRO Joint Requirements Summary

<table>
<thead>
<tr>
<th>Science or Application Element</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ecosystems [3,4]</strong></td>
<td></td>
</tr>
<tr>
<td>• Biomass Disturbance</td>
<td>Global, seasonal estimates of disturbance and regrowth</td>
</tr>
<tr>
<td>• Agriculture</td>
<td>Regional crop yield estimates surrounding growing seasons</td>
</tr>
<tr>
<td>• Wetlands and Coasts</td>
<td>Regional seasonal estimates of inundation and mangroves</td>
</tr>
<tr>
<td>• Alpine Vegetation</td>
<td>Focus on seasonal characteristics of Himalayan ecosystems</td>
</tr>
<tr>
<td>• Soil Moisture</td>
<td>Regional soil moisture surrounding growing seasons</td>
</tr>
<tr>
<td><strong>Deformation</strong></td>
<td></td>
</tr>
<tr>
<td>• Earthquake/Volcanic Cycle</td>
<td>Weekly vector sampling of deformation processes on land in plate boundary zones globally</td>
</tr>
<tr>
<td>Deformation</td>
<td>Biannual mapping of global land masses for intraplate events</td>
</tr>
<tr>
<td>• Land Subsidence, Landslides</td>
<td>Regional weekly sampling of high-priority aquifers, subsurface reservoirs, and incipient or anticipated landslides</td>
</tr>
<tr>
<td><strong>Cryosphere</strong></td>
<td></td>
</tr>
<tr>
<td>• Ice Sheet and Shelf Dynamics</td>
<td>Weekly vector sampling of deformation processes of ice sheets in winter to capture inter-annual variability</td>
</tr>
<tr>
<td>• Sea Ice Dynamics</td>
<td>Semi-weekly sampling of deformation of Arctic and Antarctic sea ice</td>
</tr>
<tr>
<td>• Sea Ice Thickness</td>
<td>Explore potential for sea ice thickness estimation</td>
</tr>
<tr>
<td>• Mountain Snow/Glacier Dynamics</td>
<td>Weekly vector sampling of deformation processes of mountain glaciers to capture inter-annual variability</td>
</tr>
<tr>
<td>• Permafrost and Freeze/Thaw</td>
<td>Explore the potential of quantifying permafrost variability and freeze/thaw transition</td>
</tr>
<tr>
<td><strong>Ocean Processes</strong></td>
<td></td>
</tr>
<tr>
<td>• Bathymetry</td>
<td>Determine shallow bathymetry in India’s coastal waters</td>
</tr>
<tr>
<td>• Wave Spectra</td>
<td>Determine ocean wave spectra in India’s coastal waters</td>
</tr>
<tr>
<td>• Coastal Winds</td>
<td>Measure high-resolution coastal winds in India’s waters</td>
</tr>
<tr>
<td><strong>Other Disasters</strong></td>
<td></td>
</tr>
<tr>
<td>• E.g. Floods, Oil Slicks, Fires</td>
<td>As natural disasters unfold, direct observation resources and accelerate dissemination of data to users</td>
</tr>
</tbody>
</table>
# Societal Challenges and What a Dual Frequency SAR Could Contribute

<table>
<thead>
<tr>
<th>Challenge</th>
<th>SAR Benefit Through Regular Monitoring of:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Food Security</td>
<td>- Soil moisture and crop growth at agricultural scale</td>
</tr>
<tr>
<td></td>
<td>- Desertification at regional scales</td>
</tr>
<tr>
<td>Freshwater Availability</td>
<td>- Aquifer use/extent regionally</td>
</tr>
<tr>
<td></td>
<td>- Water-body extent changes</td>
</tr>
<tr>
<td></td>
<td>- Glaciers serving as water sources</td>
</tr>
<tr>
<td>Human Health</td>
<td>- Moisture and vegetation as proxy for disease and infestation vectors</td>
</tr>
<tr>
<td>Disaster Prediction &amp; Response</td>
<td>- Regional building damage and change assessment after earthquakes</td>
</tr>
<tr>
<td></td>
<td>- Earthen dams and levees prone to weakening</td>
</tr>
<tr>
<td></td>
<td>- Volcanoes, Floods, Fires, Landslides</td>
</tr>
<tr>
<td>Climate Risks and Adaptation</td>
<td>- Ice sheet dynamics and changes in sea-ice cover</td>
</tr>
<tr>
<td></td>
<td>- Coastal erosion and shoreline migration</td>
</tr>
<tr>
<td>Urban Management and Planning</td>
<td>- Urban growth through coherent change detection</td>
</tr>
<tr>
<td></td>
<td>- Building deformation and urban subsidence</td>
</tr>
<tr>
<td>Human-activity Based Climate Change</td>
<td>- Deforestation’s influence on carbon flux</td>
</tr>
<tr>
<td></td>
<td>- Oil and gas reservoirs</td>
</tr>
</tbody>
</table>
A NASA-ISRO SAR Mission Could Provide Needed Data for 9 of 13 Grand Challenge Hazards
Basic Geodetic & Imaging Measurements

Interferogram

Decorrelation

Polarimetry
DESDynI Synthetic Aperture Radar Concept

- Dual Frequency: L- and S-Band
- Primary Modes:
  - Solid earth deformation, ice sheets and glaciers: Single-Pol (HH or VV)
  - Ecosystems: Dual, Quad, Quasi-Quad Pol
  - Sea-ice: Low-BW Single-Pol (VV)
- Data acquired Left or Right of spacecraft track, ascending and descending
  - Wide swath in all modes would allow for 12 day repeat with overlap at equator (2-5 passes over a site depending upon latitude)
  - Mode used over any given area selected based on science need
  - Mode conflicts resolved through plan optimization
Benefits of both L-band and S-band

- Global L-band data with unprecedented spatial and temporal sampling would drive new directions in science and applications, responsive to the Decadal Survey
- Globally distributed but targeted measurements at S-band for science applications would be a fundamentally new data set
- Combination of simultaneous S-band and L-band data would be extremely powerful for discriminating differential scales in many disciplines
- Greater available bandwidth at S-band than L-band could enable focus on some areas at finer resolution

SIR-C/X-SAR observes Weddell Sea ice, Antarctica

SIR-C/X-SAR over Los Angeles
Multi-frequency Data over Agricultural Regions

Wheat Fields
Dnieper River, Ukraine

Red: LHH
Green: LHV
Blue: CHV

Rubber, banana and oil palm trees
Muar, Malaysia
NASA-ISRO SAR Mission Concept

- Mission concept
  - L- and S-band Synthetic Aperture Radar (SAR)
  - Sweep SAR technique (large swath) for global data collection
  - 12-day repeat, 98-deg inclination, sun-synch orbit
  - 3 years science operations (5 years consumables)
  - Science downlink: NASA Ka-band TDRSS (all data) and ISRO Ka-band ground station (subset)
  - Primary instrument: NASA/JPL L-band SAR
  - Secondary instrument: ISRO S-band SAR
  - Spacecraft: ISRO I3K
  - Launch vehicle: ISRO GSLV
Spacecraft Concept - Animated
Proposed Radar Payload & Flight System Configuration

IRIS
(Integrated Radar Instrument Structure)

<table>
<thead>
<tr>
<th>FRAp</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Feed RF Aperture)</td>
</tr>
</tbody>
</table>

L
S

1194mm Payload Interface Ring

L-Band SAR Electronics, SSR, GPS-Rx
(on IRIS +Y & -Y Decks)

S-Band SAR Electronics
(on IRIS Nadir Deck)

Radar Payload
= IRIS + RBA (Reflector/Boom Assembly with integrated GPS-Ant/LNA)

RBA Stowed Boom
(multiple segments wrapping IRIS)

RBA Stowed Reflector
(with Launch Restraints on IRIS Nadir Deck)

GPS-Ant/LNA
(on RBA Boom)

Pre-decisional – for Planning and Discussion Purposes Only
Proposed Radar Payload & Flight System Configuration

Integrated Observatory \textit{(Spacecraft + Radar Payload)}

Launch Configuration

IRIS length: \textbf{3453}

Radar Payload stowed length: \textbf{3736}

Flight System: \textbf{5024}

\textbf{Flight System in Launch Configuration (GSLV)}

Pre-decisional – for Planning and Discussion Purposes Only
Proposed Mission Timeline

Months

0 1 2 3 4 5 6

Years

1 2 3

Launch

Deployments

Commissioning

Science Operations 3 years

De-commissioning

Pre-decisional – for Planning and Discussion Purposes Only
L-Band Deformation (Every Cycle) Science Targets
L-Band Ecosystems Science Targets
L-Band (blue) and S-Band (purple) Ice Science Targets
## Primary SAR Instrument Modes

**DSI-I2S-4g14-018 / 13 June 2013**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Solid Earth - Deformation (soil)</td>
<td>L</td>
<td>SP HH</td>
<td>20±5</td>
<td>1650</td>
<td>25</td>
<td>833</td>
<td>333</td>
<td>timeline-dependent heater only</td>
</tr>
<tr>
<td>2</td>
<td>Dynamics of Ice - Land Ice</td>
<td>L</td>
<td>SP HH</td>
<td>20±5</td>
<td>1650</td>
<td>25</td>
<td>833</td>
<td>330</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Dynamics of Ice - Priority Ice</td>
<td>L</td>
<td>SP HH</td>
<td>80</td>
<td>1650</td>
<td>40</td>
<td>931</td>
<td>1052</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Dynamics of Ice - Sea Ice</td>
<td>L</td>
<td>SP VV</td>
<td>5</td>
<td>1650</td>
<td>20</td>
<td>801</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Ecosystem Structure (shrubs)</td>
<td>L</td>
<td>QP HH/HV/VH/VV</td>
<td>40</td>
<td>1550*</td>
<td>40</td>
<td>1237</td>
<td>1835</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Ecosystem Structure (shrubs)</td>
<td>L</td>
<td>Quasi-Quad</td>
<td>40±40</td>
<td>1650</td>
<td>40</td>
<td>1270</td>
<td>2092</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Ecosystem Structure (shrubs)</td>
<td>L</td>
<td>DP HH/HV</td>
<td>40</td>
<td>1650</td>
<td>40</td>
<td>995</td>
<td>1052</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Ecosystem Structure (shrubs)</td>
<td>L</td>
<td>CP RH/RV</td>
<td>40</td>
<td>1650</td>
<td>40</td>
<td>1270</td>
<td>1108</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>S-Band SE, ES, DI (shrubs)</td>
<td>S</td>
<td>Quasi-Quad</td>
<td>37.5</td>
<td>1800†</td>
<td>40</td>
<td>3144</td>
<td>2551</td>
<td>1939</td>
</tr>
<tr>
<td>13</td>
<td>S-Band Coastal Winds (ocean)</td>
<td>S</td>
<td>DPTx HH/HV</td>
<td>25</td>
<td>1850†</td>
<td>25</td>
<td>2488</td>
<td>1895</td>
<td>694</td>
</tr>
<tr>
<td>14</td>
<td>S-Band SE, ES, DI (shrubs)</td>
<td>S</td>
<td>CP RH/RV</td>
<td>25</td>
<td>1850†</td>
<td>25</td>
<td>2488</td>
<td>1895</td>
<td>694</td>
</tr>
<tr>
<td>15</td>
<td>Solid Earth - Deformation (soil)</td>
<td>L+S</td>
<td>DP HH/HV</td>
<td>40</td>
<td>1650^</td>
<td>40^</td>
<td>2763</td>
<td>1768</td>
<td>1524</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L+S</td>
<td>CP RH/RV</td>
<td>25</td>
<td>1850^</td>
<td>25^</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Ecosystem Structure (shrubs)</td>
<td>L+S</td>
<td>QP</td>
<td>20</td>
<td>1500**A</td>
<td>25^</td>
<td>3670</td>
<td>2627</td>
<td>1984</td>
</tr>
<tr>
<td>17</td>
<td>Ecosystem Structure (shrubs)</td>
<td>L+S</td>
<td>QP</td>
<td>40</td>
<td>1500**A</td>
<td>40^</td>
<td>4994**</td>
<td>3774</td>
<td>4919</td>
</tr>
</tbody>
</table>

**Notes:**
- PRF is per each Tx polarization; for Quad-Pol or Dual Co-Pol with interleaved Tx, effective timing is 2 x PRF
- for joint dual-frequency modes, L-Band and S-Band must use a common PRF and blanking PW
- PRF selected by JPL performance tool to maximize swath; SAC may change to different value based on their performance criteria
- **to be assessed relative to available peak power from S/C Power Subsystem**

Nominal modes for Multi-Mode mission simulation scenario; *changes for sim003 (pseudo-sim002.5) in red*

Nominal modes for Radar Always-On reduced-mode mission simulation scenario

Pre-decisional – for Planning and Discussion Purposes Only
Mode Profile for Nominal Science Operations

- DSI-I12S-4g8-015 / SimM002-Q3 / SDT 17 May 2013

On time per mode per orbit for observation file:
observations simMulti 002.txt

- Ecosystems
- Sea Ice
- Land Ice
- ISRO SolidEarth / Agriculture / Ice (S-Band QQP)
- ISRO Ocean (S-Band DPTx)
- ISRO SolidEarth / Ag / Ice (Joint L QP + S CP)

Duration [sec]

Orbit number

Mode number

Pre-decisional – for Planning and Discussion Purposes Only
Summary and Next Steps

• The NASA-ISRO mission concept could be an exciting addition to the international constellation of SAR missions
  - Reliable, regular, and frequent L-band observations
  - Free, open access to data
  - Dense temporal and spatial sampling over the globe
  - Additional S-band data to extend the range of sensitivity in critical areas

• Project preparing for a Mission Concept Review in Fall 2013

• If successful, partnership approach would be developed in Phase A
Backup
L-Band: Base Map Coverage Summary – 100%
L-Band: Ecosystems Coverage Summary – 100%
L-Band: Deformation Coverage Summary – 100%
L-Band: Ice Coverage Summary – 88-100%
S-Band: Coverage Summary – 100%