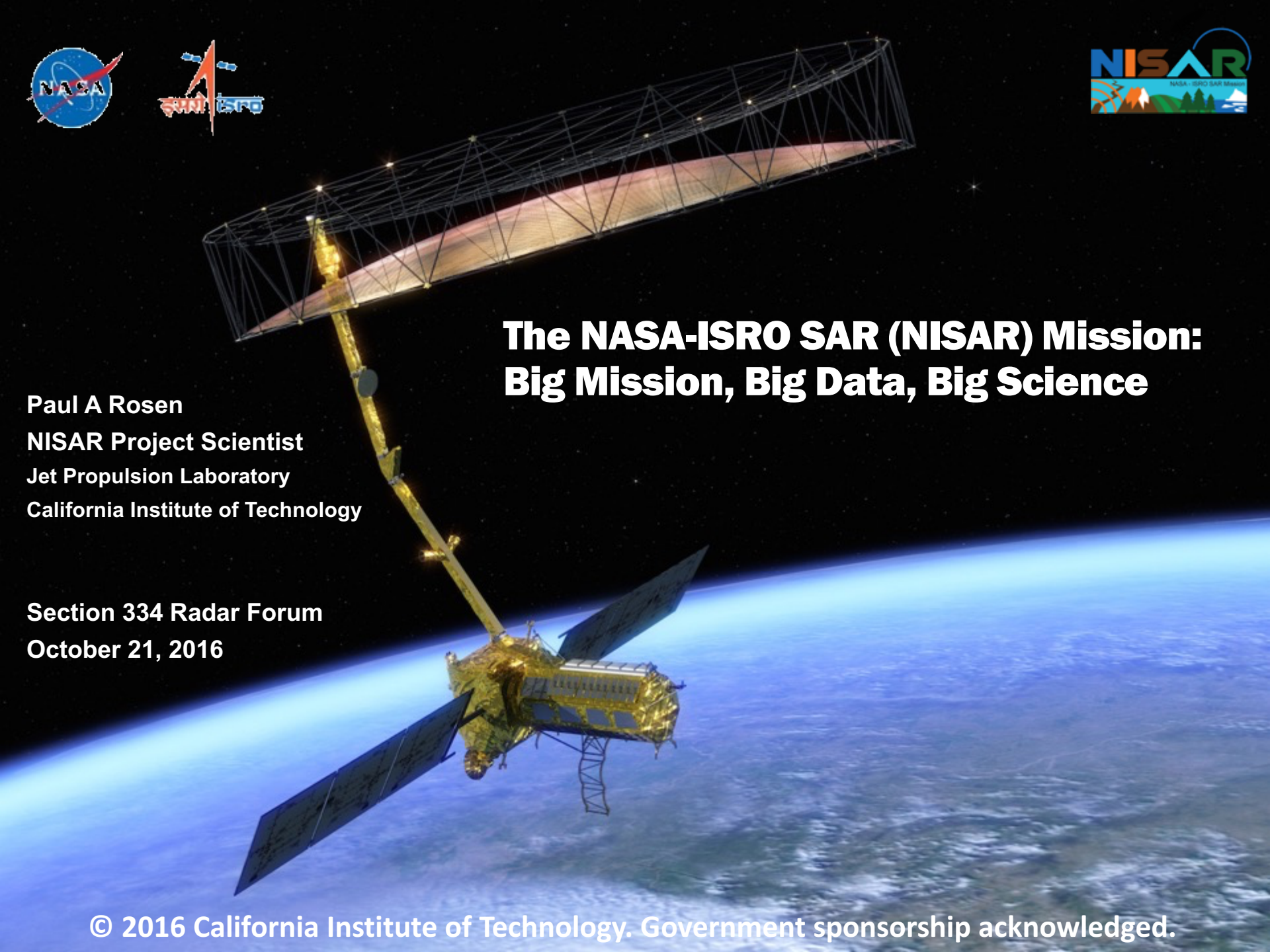

The NASA-ISRO SAR (NISAR) Mission: Big Mission, Big Data, Big Science

Paul A Rosen
NISAR Project Scientist
Jet Propulsion Laboratory
California Institute of Technology

Section 334 Radar Forum
October 21, 2016

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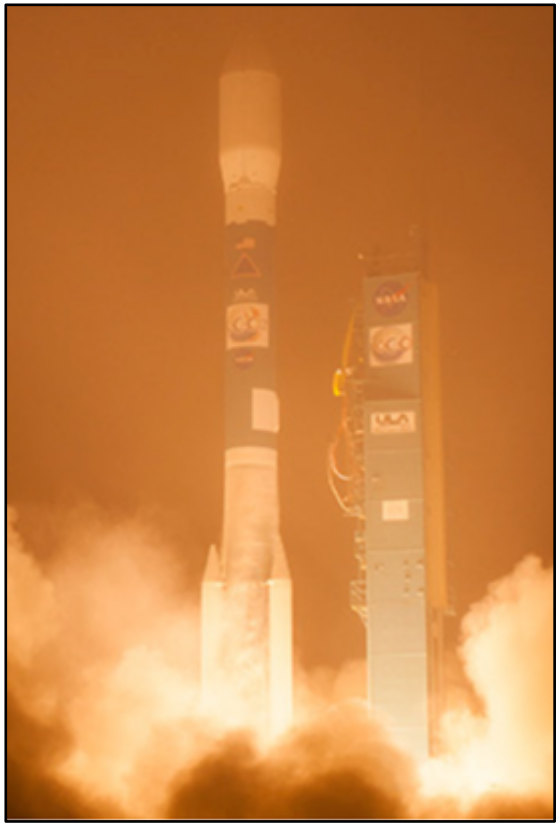
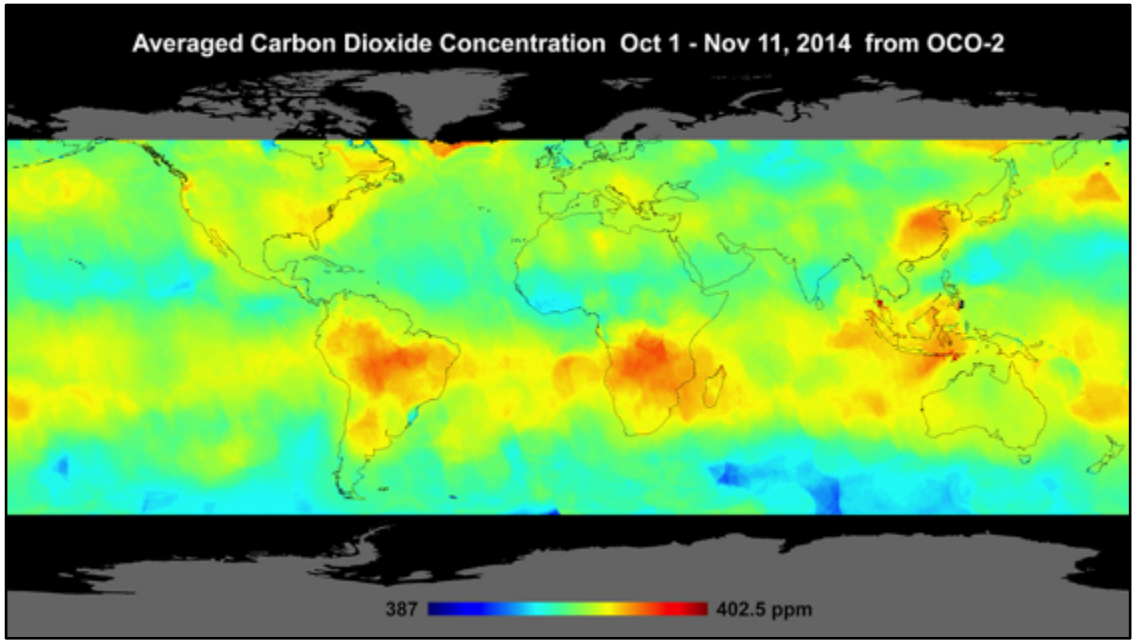
OCO-2: Making Monthly Maps of Carbon Dioxide



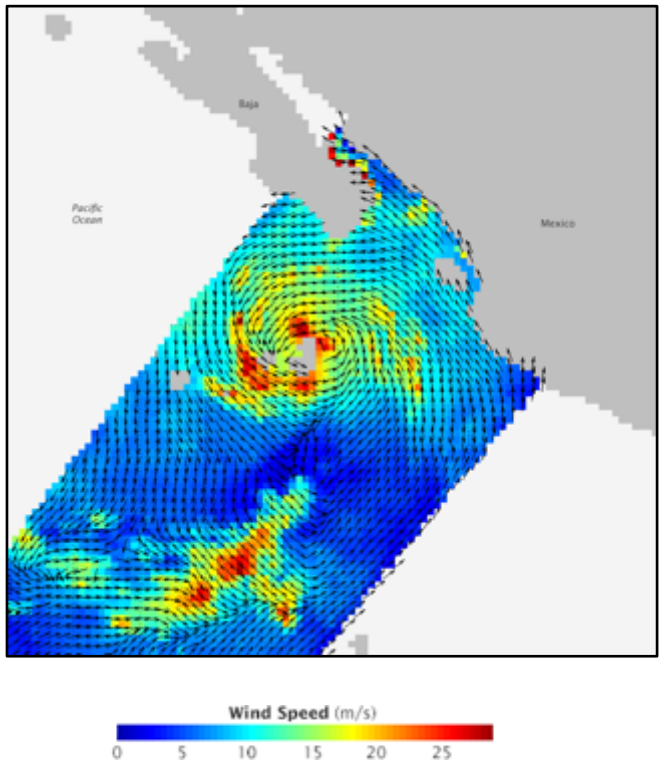
Launch: July 2, 2014



First Global Map: December 18, 2014

RapidScat: Making Daily Maps of Winds over the Ocean

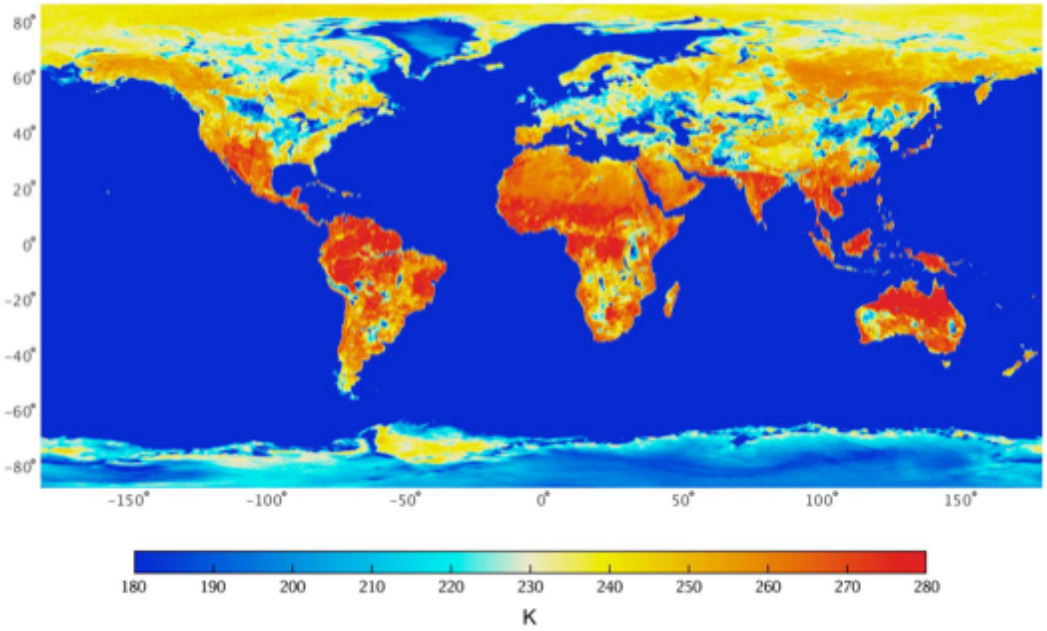
Installation on International Space Station: September 30, 2014



First Light: October 3

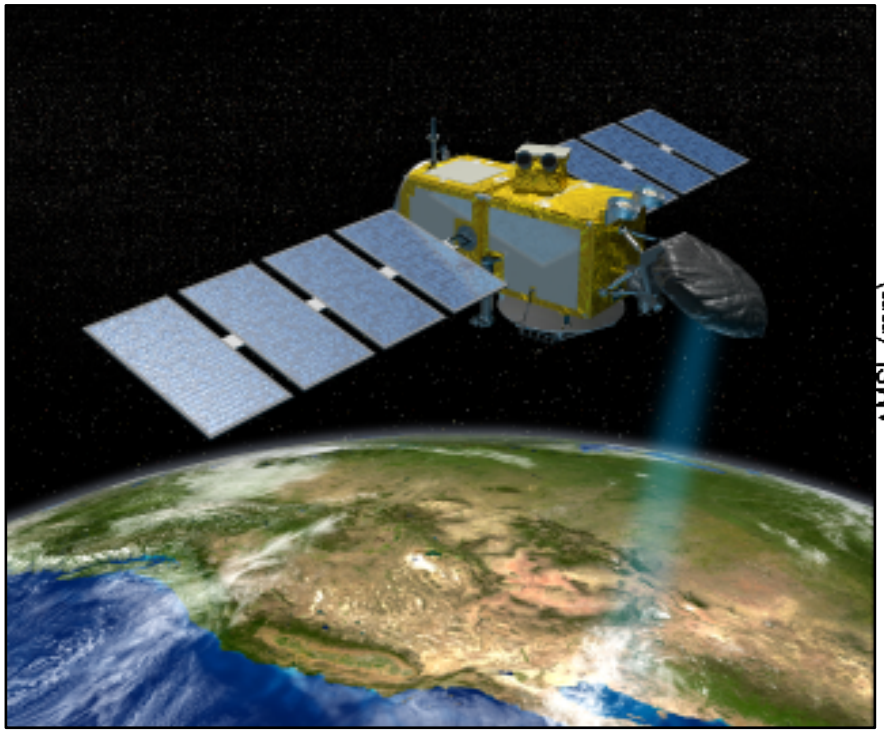
SMAP: Measuring Soil Moisture Globally every 3 Days

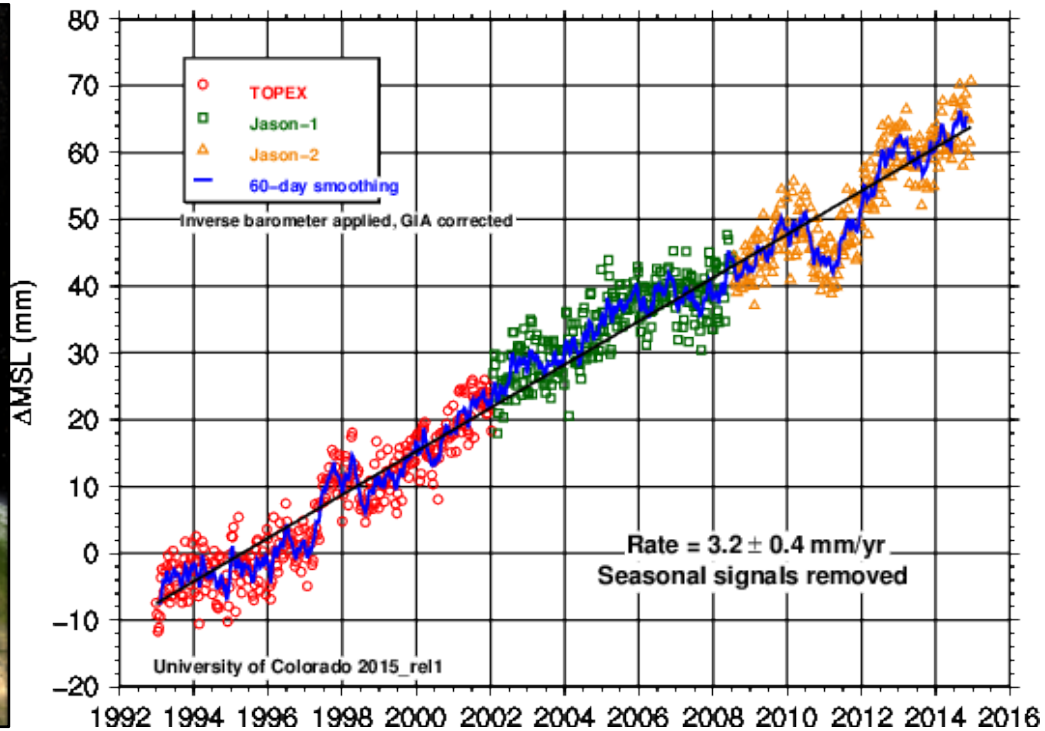
Launch: January 31, 2015



First Brightness Temperature Product:
March 31 – April 3, 2015

Jason 3: Continuing the Record of Sea Level Rise

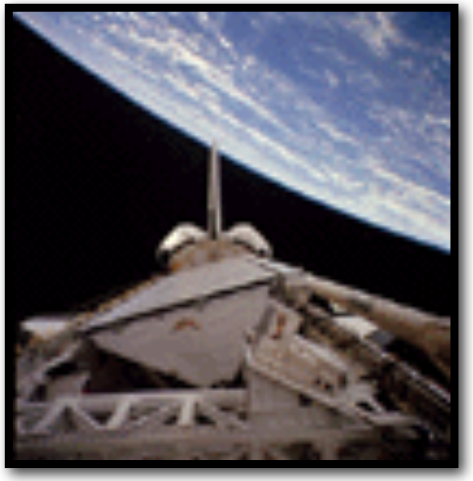


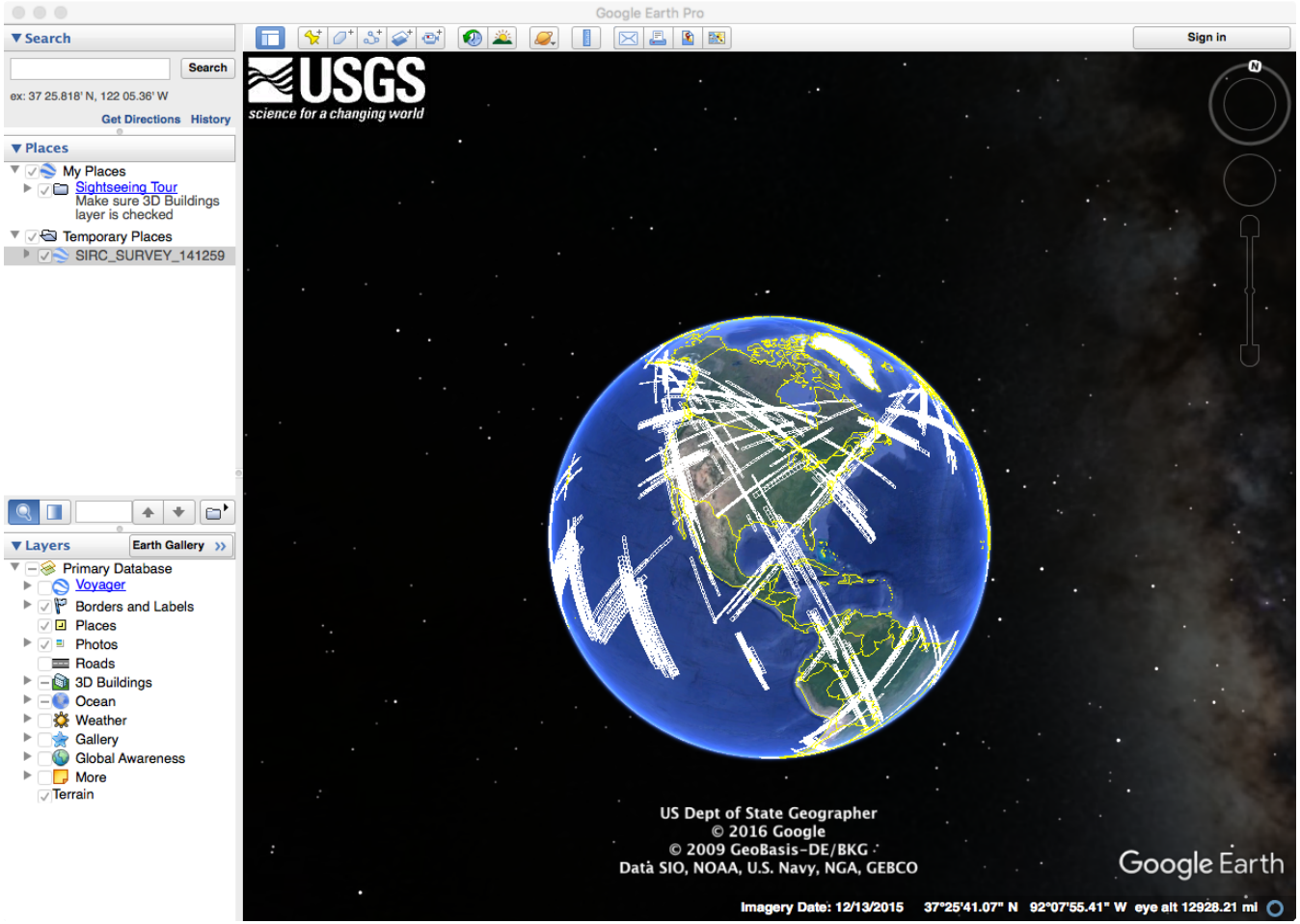


Launch Date: July 22, 2015

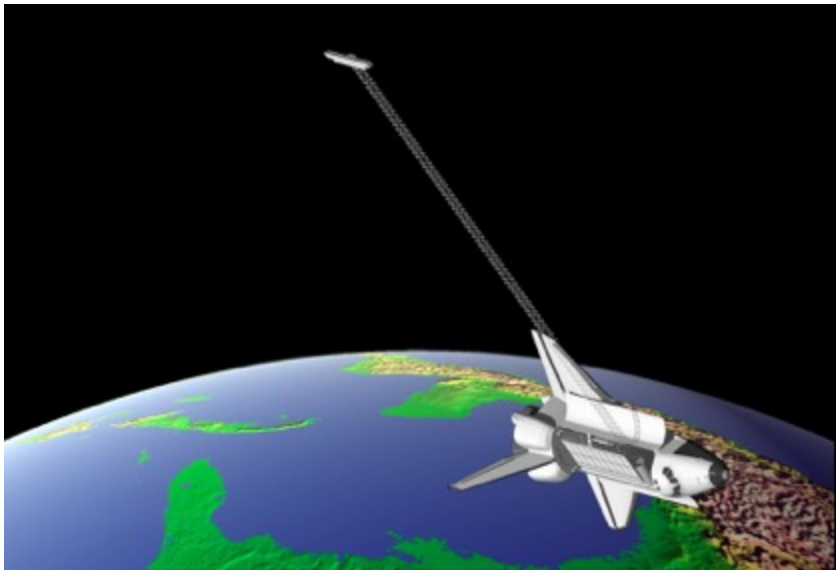
SAR Coverage… Not So Much
SIR-C Coverage Survey

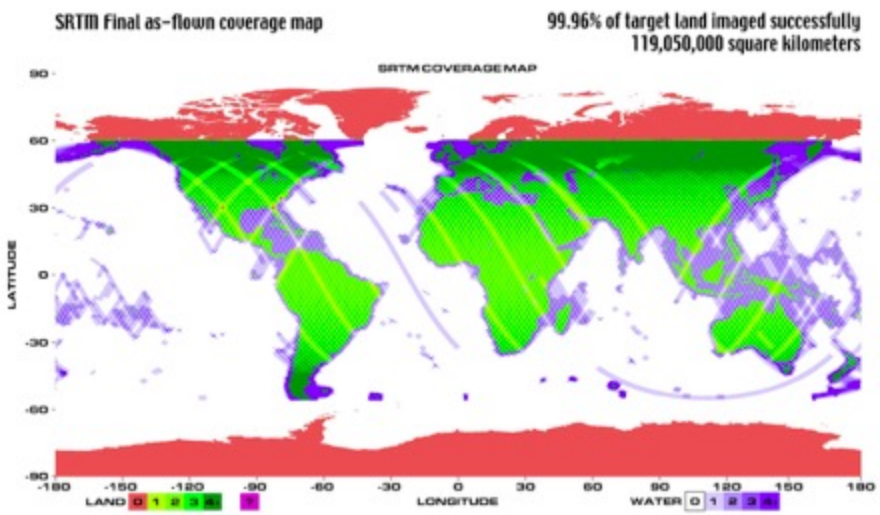
SIR-C





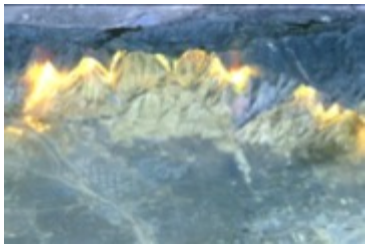
SRTM Mission





On February 11, 2000, SRTM aboard the Space Shuttle Endeavour was launched to perform 3-dimensional mapping of 80% of the Earth's land surface. This 11-day mission was successfully concluded with 99.96% of the planned area mapped with at least one pass. This mission is the world first demonstration of a single pass SAR interferometry. The final topographic products include an elevation map and radar images in digital format, produced by the 334-developed interferometric SAR processing system.

The Need for Better SAR Sampling in Earth Science and Applications - Capturing the Earth in Motion



- *Dense temporal and spatial sampling*
  - Reveals the mechanisms that drive poorly understood surface processes
    - Fast-transients on Ice sheets and glaciers
    - Disturbance and recovery in forests
    - Tracking evolving hazards
- C*omprehensive* global measurements
  - Of ice to improve climate projection accuracy
  - Of ecosystems to reduce land carbon flux uncertainties
  - Of solid earth to improve disaster forecasting and risk assessments
- *Targeted* regional measurements
  - New science
  - New applications
  - Hazard response

Toward Global Sampling with SAR

- Since SEASAT in 1978, the US science community has been looking forward to a free-flying SAR mission
- It has not been for lack of trying:
  - Selected community recommendations:
    - 1994 Letter to NASA ESD recommending a free-flying SAR at L-band in 8-day repeat
    - 2002 SESWG Report ”InSAR everywhere all the time”
    - 2002 EarthScope Executive Committee recommending InSAR as the 4th pillar of EarthScope
    - 2004 SAR Workshop and Report recommending L-band Polarimetric SAR
    - 2007 Decadal Survey recommending DESynI long-wavelength polarimetric radar
  - Proposals
    - 1994-1995 SIR-C free-flyer proposal
    - 1996 LightSAR commercial/science dual use L-band and X-band earmark
    - 1996 ESSP ECHO-1
    - 1998 ESSP ECHO-2
    - 2002 ESSP ECHO-3
    - 2004 InSAR Satellite Concept
    - 2004-2007 defense/science dual use broad-band SAR
    - 2007-2011 DESDynI L-band SAR

NISAR Science Overview and Program Context

- NRC Decadal Survey recommended a DESDynI Mission for near-term launch to address important scientific questions of high societal impact.
- NASA's Climate Architecture identified the radar's important role in climate (cryosphere and carbon) and water cycle science.

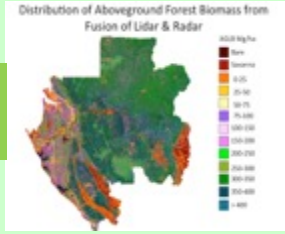
- The NASA NISAR Science Definition Team has developed a set of integrated requirements to respond to the Climate Architecture and other important questions, with ISRO Science participation

- **Dynamics of Ice: Ice sheets, Glaciers, 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 glaciers changing in relation to climate?*
- **Ecosystems and Biomass Change**
  - *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 Deformation: Hazard Response**
  - *Which major fault systems are nearing release of stress via strong earthquakes?*
  - *Can we predict future eruptions of volcanoes?*
  - *What are optimal remote sensing strategies to mitigate disasters and monitor/manage water and hydrocarbon extraction and use*
- **Coastal Processes: India**
  - *What is the state of important mangroves?*
  - *How are Indian coastlines changing?*
  - *What is the shallow bathymetry around India?*
  - *What is the variation of winds in India's coastal waters?*

NISAR Mission Overview

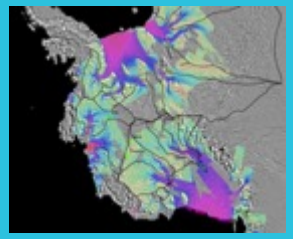
Mission Science

Ecosystem Structure



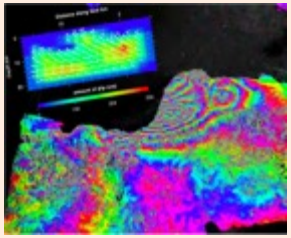
Biomass disturbance; effects of changing climate on habitats and CO_2

Cryosphere



Ice velocity, thickness; response of ice sheets to climate change and sea level rise

Solid Earth

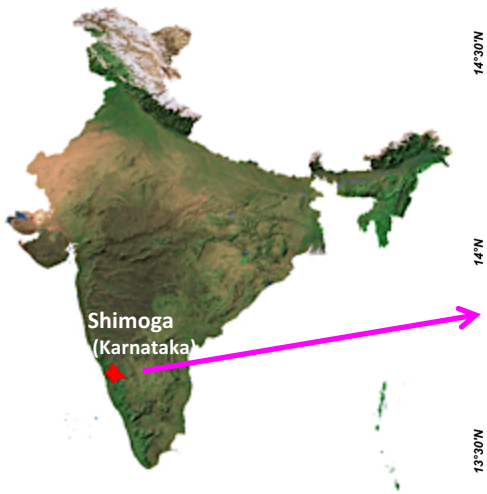


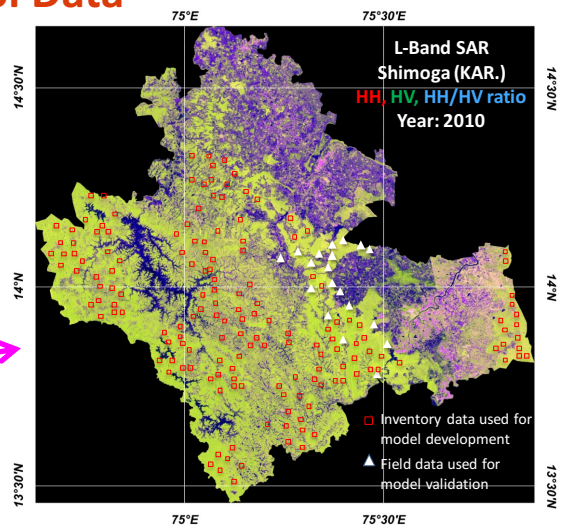
Surface deformation; geo-hazards; water resource management

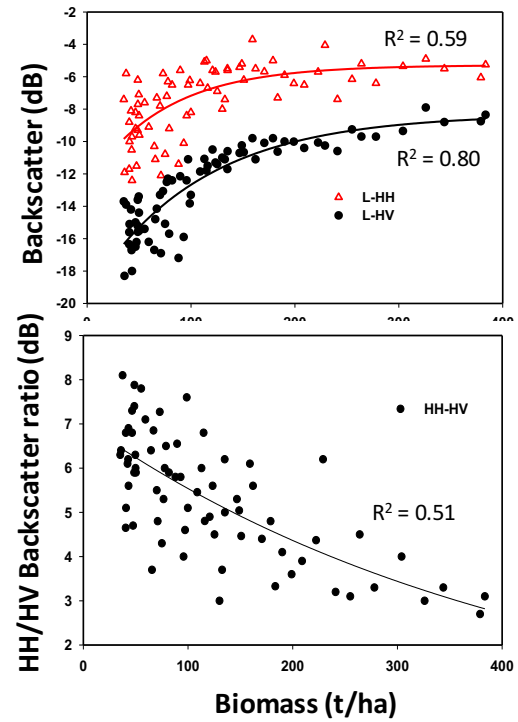
- Directed mission within the Earth Systematic Missions Program under NASA Earth Science Division
- Category 2 project (NPR 7120.5E) and Payload risk class C (NPR 8705.4)
- Major international partner: Indian Space Research Organisation (ISRO)
- Baseline launch date: No earlier than December 2020
- Dual frequency L- and S-band Synthetic Aperture Radar (SAR)
  - L-band SAR from NASA and S-band SAR from ISRO
  - 5-10 m resolution polarimetric imagery
- Sweep SAR technique (large swath) for global data collection
- Baseline orbit: 747 km altitude circular, 98 degrees inclination, sun-synchronous, dawn-dusk (6 AM–6 PM), 12-day repeat
- Repeat orbit within ± 250 m
- Spacecraft: ISRO I3K (flown at least 9 times)
- Launch vehicle: ISRO Geosynchronous Satellite Launch Vehicle (GSLV) Mark-II (4-m fairing)
- 3 years science operations (5 years consumables)
- *All science data (L- and S-band) will be made available free and open, consistent with the long-standing NASA Earth Science open data policy*

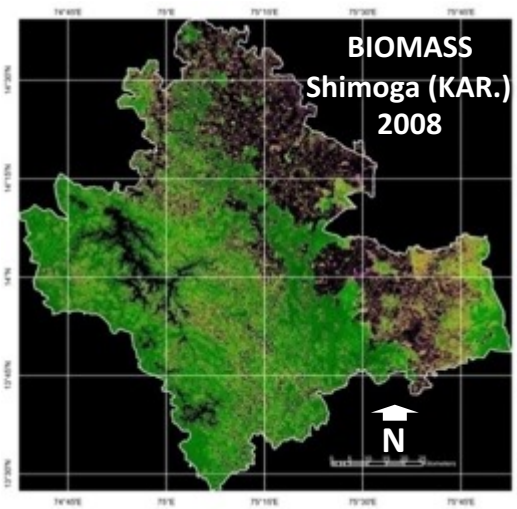
NISAR facilitates above-ground biomass of Indian forests more frequently with better accuracy

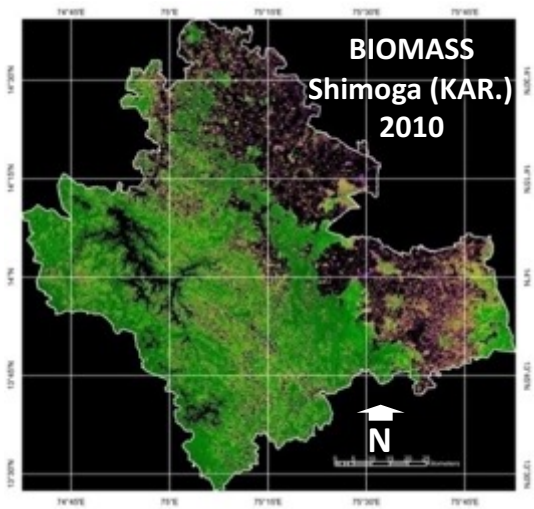
ALOS PALSAR-1 HH+HV pol Data











Biomass (ton/ha) (Deciduous forest dominated by teak (*Tectona grandis*) vegetation)

No forest | < 20 | 20 – 50 | 50 – 80 | 80 – 120 | 120 – 160 | > 160

$$Y_{BIOMASS\ (t/Ha)} = A + (B * \sigma^0_{HV}) + (C * \sigma^0_{HH\text{-}HV})$$

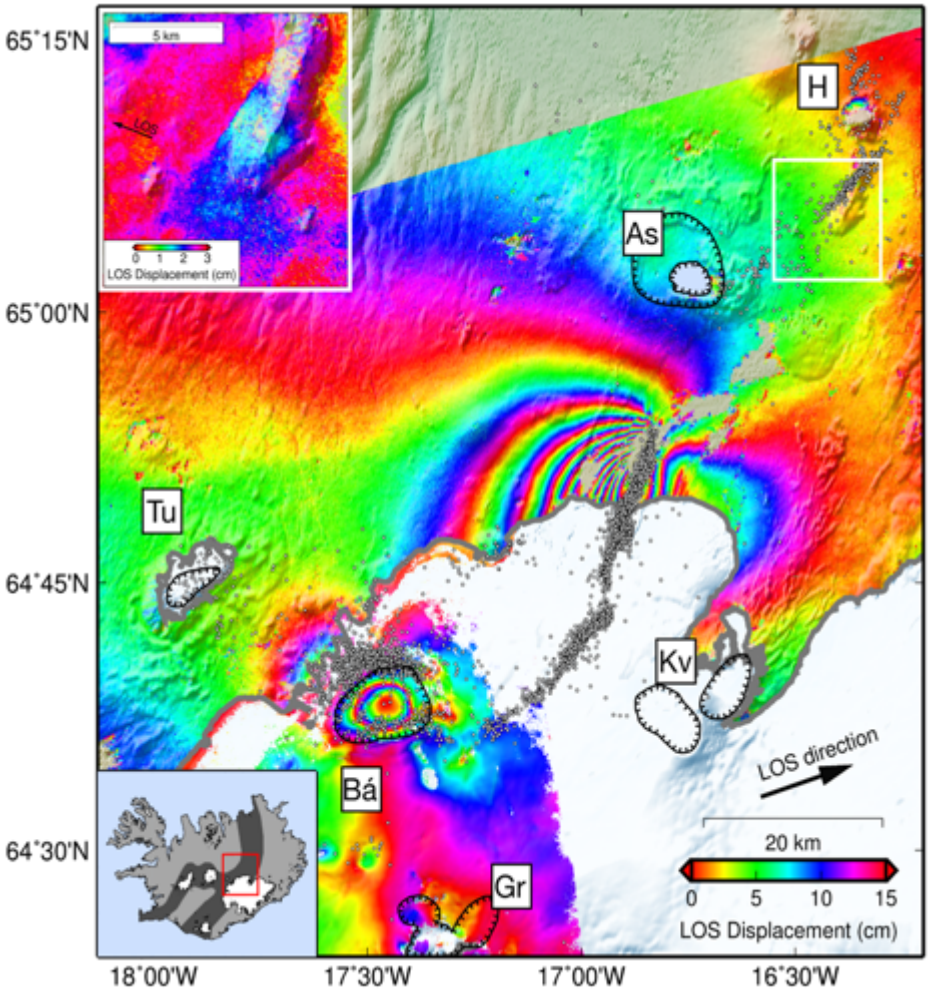
$\sigma\sigma^0$ is backscattering coefficient in dB and A, B and C are the model coefficients

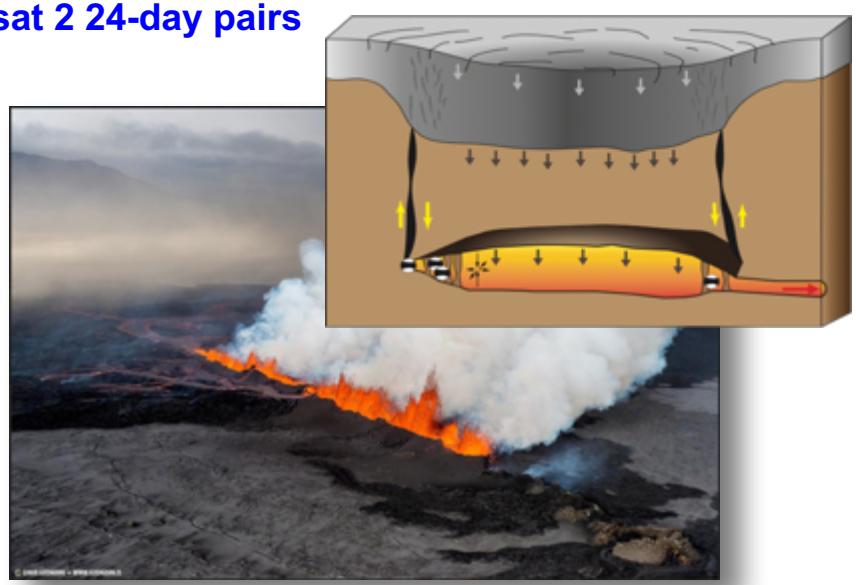
(RMS Error < 25 t/ha for biomass range within 120 t/ha)

model coefficients (A,B & C) have been calculated for different types of forests at several bio-climatic regions

Collapse of Bárdabunga Caldera (Iceland) & associated plate boundary rifting

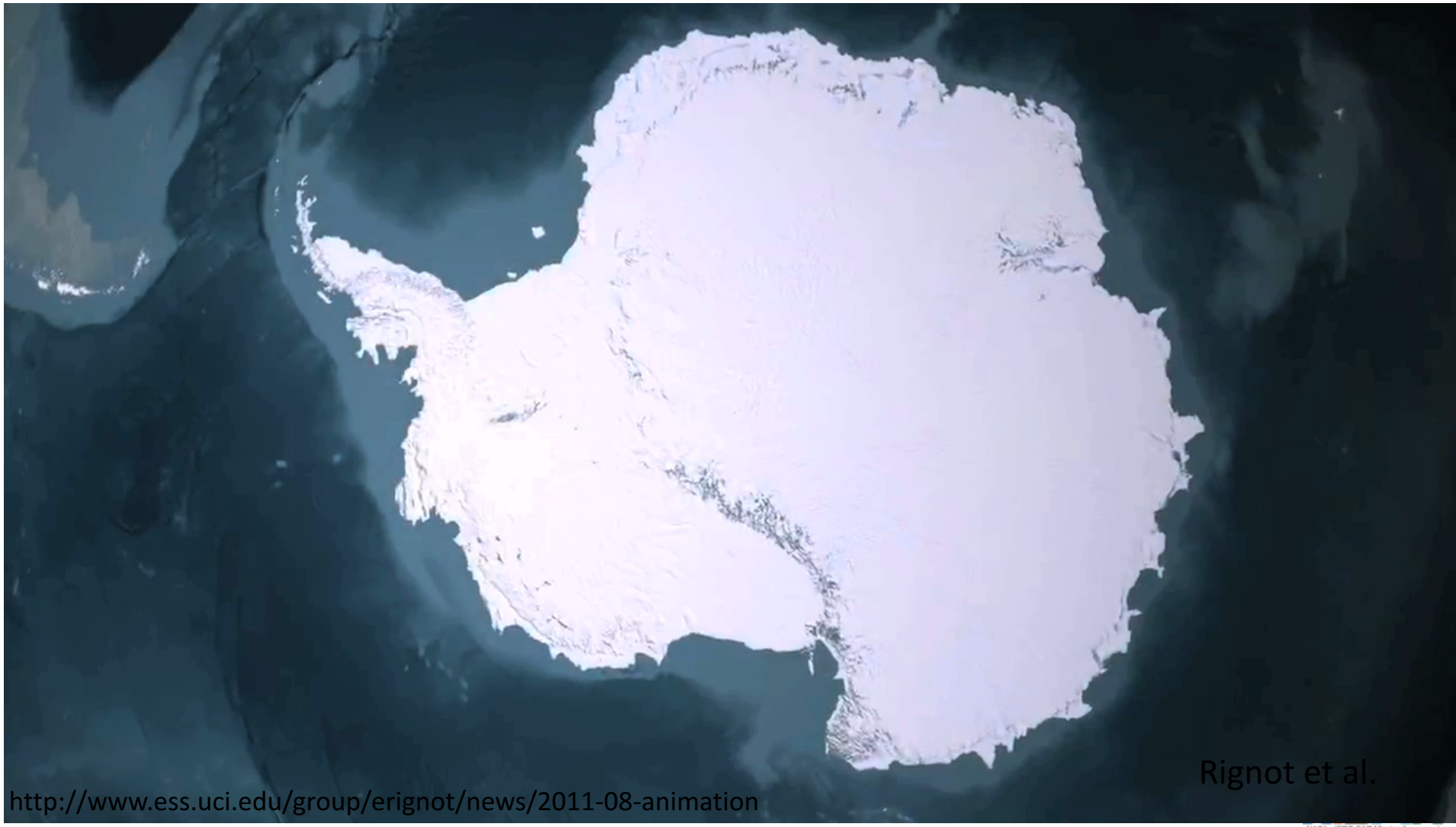
Fast Sampling (COSMO-SkyMed 1-day) fills in Radarsat 2 24-day pairs





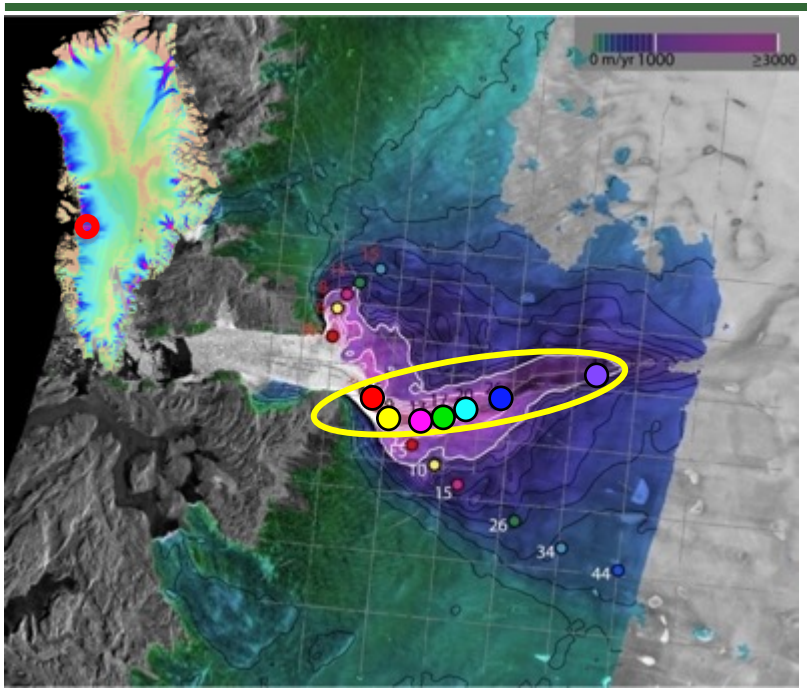
Riel et al., *Geophys. J. Int.*, 2015

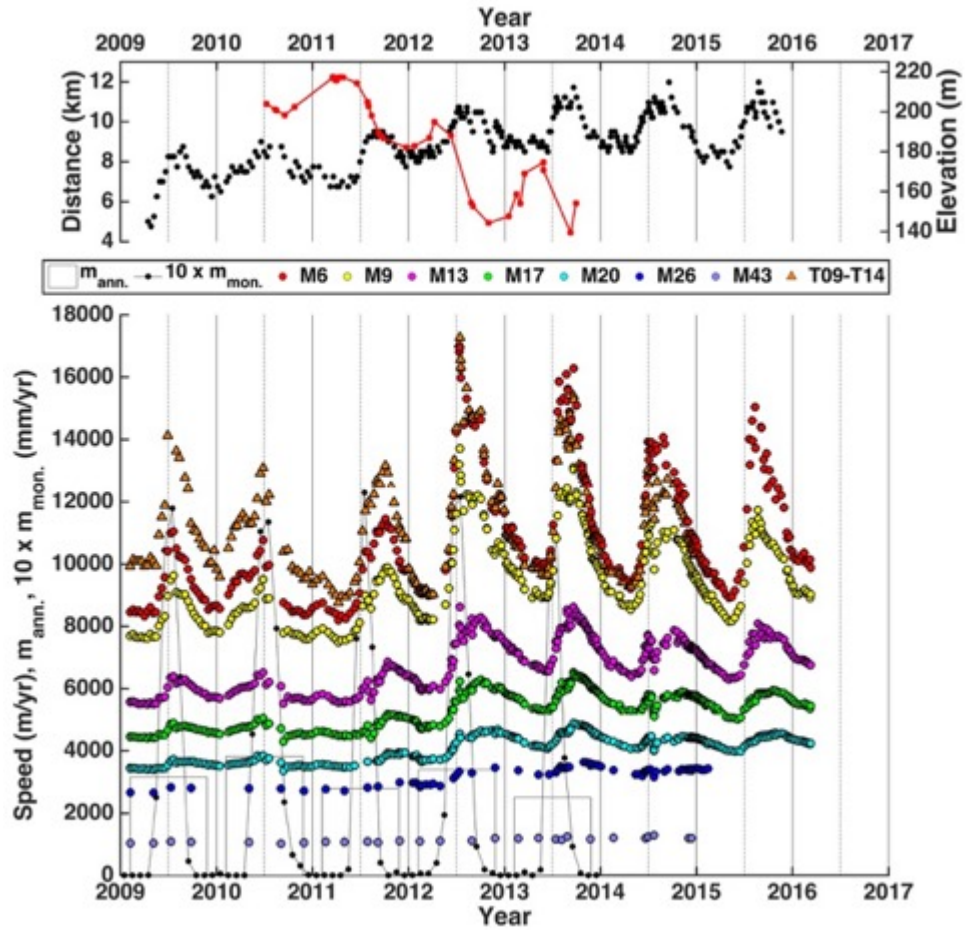
Dynamic Ice Sheets



http://www.ess.uci.edu/group/erignot/news/2011-08-animation

Cryosphere – Dynamic Ice Sheets



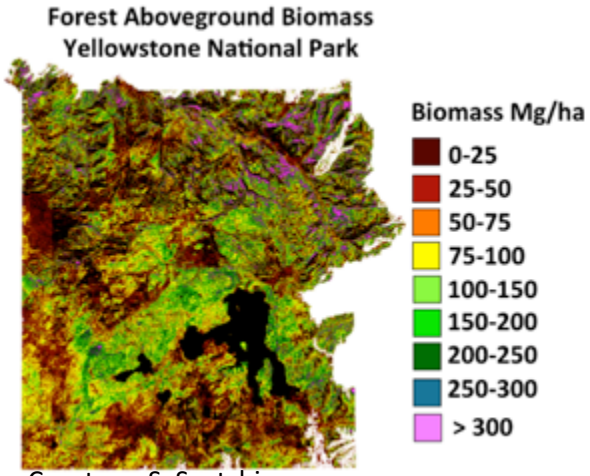


Jakobshavn Isbrae

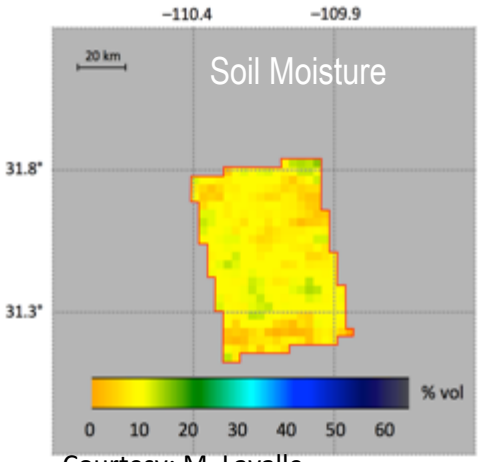
Update to Joughin et al., 2014

Requires time-varying horizontal velocities at near-weekly sampling intervals in areas of potential rapid or seasonal change to an accuracy better than 3% plus 10 m/yr (1-sigma) at 500-m resolution (> 80% coverage)

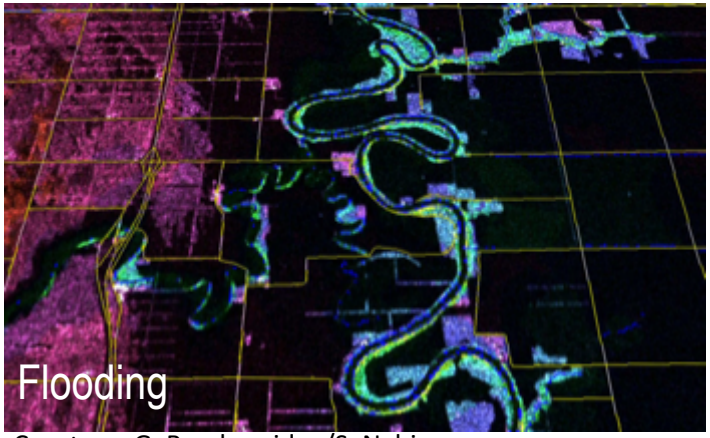
Some NISAR Applications Products



Courtesy: S. Saatchi

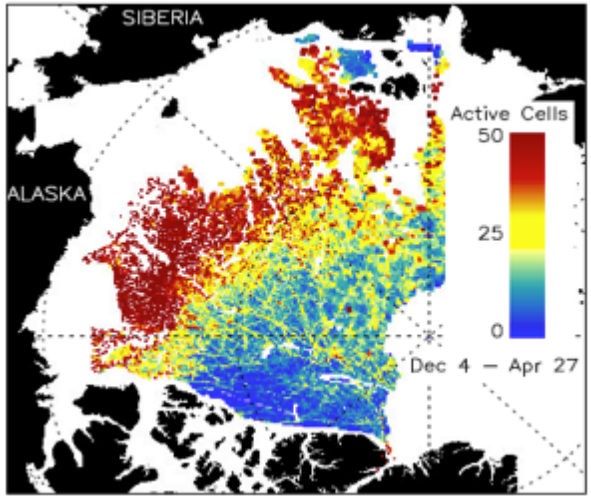


Courtesy: M. Lavalle



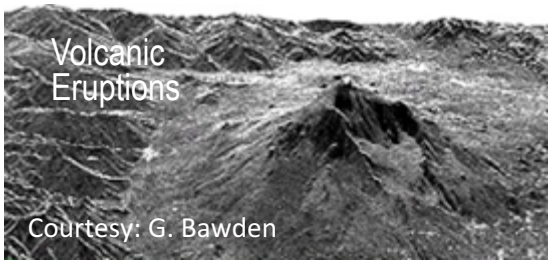
Courtesy: G. Breckenridge/S. Nghiem

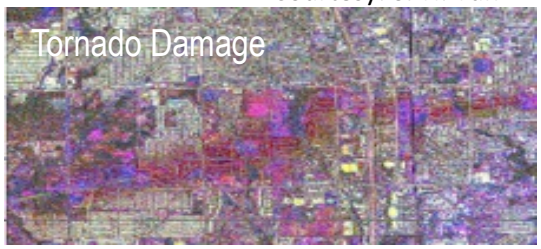
Courtesy: S.-H. Yun

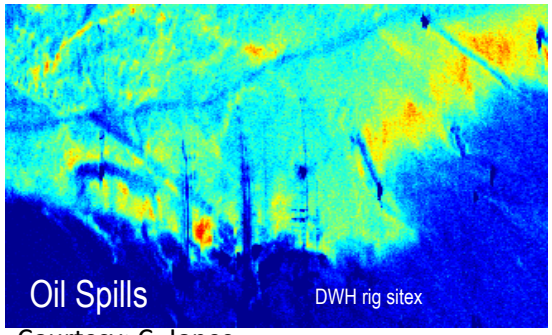


Courtesy: R. Kwok

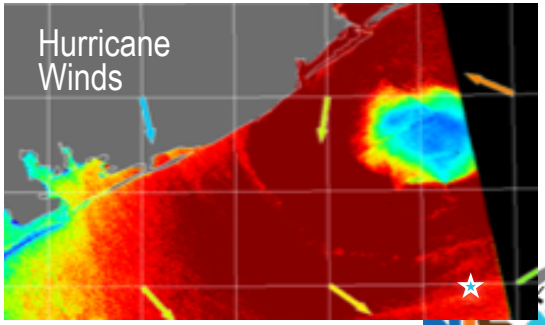
Sea Ice Extent/ Ice and Ship Tracking







Courtesy: C. Jones



Courtesy: G. Bawden

Level-2 Solid Earth Science Requirements Summary

Attribute	Secular Deformation (658)	Co-Seismic Deformation (660)	Transient Deformation (663)
Measurement	Spatially averaged relative velocities in two dimensions	Point-to-point relative displacements in two dimensions	Point-to-point relative displacements in two dimensions
Method	Interferometry, Speckle tracking	Interferometry, Speckle tracking	Interferometry, Speckle tracking
Duration	3 years	3 years	Episodic over mission, depending on science target
Product resolution	100 m; smoothed according to distance scale L	100 m	100 m
Accuracy	2 mm/yr or better, 0.1 km < L < 50 km, over > 70% of coverage areas	4 $(1+L^{1/2})$ mm or better, 0.1 km < L < 50 km, over > 70% of coverage areas	3 $(1+ L^{1/2})$ mm or better, 0.1 km < L < 50 km, over > 70% of ~2,000 targeted sites
Sampling	One estimate over 3 years, two directions	4 times per year to guarantee capture of any earthquake on land before surface changes too greatly	Every 12-days, two directions
Coverage	Land areas predicted to move faster than 1 mm/yr	All land, as earthquake locations are unknown *a priori*	Post-seismic events, volcanoes, ground-water, gas, hydrocarbon reservoirs, landslide-prone
Response latency	N/A	24 hour tasking, 5 hour data delivery Best effort basis on event	24/5 Best effort basis on event

Level-2 Cryosphere Science Requirements Summary (1/2)

Attribute	Ice Sheets and Glaciers Velocity Slow Deformation (667)	Ice Sheets and Glaciers Velocity Fast Deformation (668)	Ice Sheet Time-Varying Velocity (738)
Measurement	Point-to-point displacements in two dimensions	Point-to-point displacements in two dimensions	Point-to-point relative horizontal displacements
Method	Interferometry, Speckle tracking	Interferometry, Speckle tracking	Interferometry, Speckle tracking
Duration	3 years	3 years	3 years
Product resolution	100 m	250 m	500 m
Accuracy	3% of the horizontal velocity magnitude plus 1 m/yr, or better, over > 90% of coverage areas	3% of the horizontal velocity magnitude plus 5 m/yr, or better, over > 90% of coverage areas	3% of the horizontal velocity magnitude plus 10 m/yr, or better, over > 80% of coverage areas
Sampling	Each cold season, two directions	Each cold season, two directions	Every 12-days, two directions
Coverage	Areas moving slower than 50 m/yr of both poles and glaciers and icecaps	Areas moving faster than 50 m/yr of both poles	Outlet glaciers, or other areas of seasonal change
Response latency	N/A	N/A	24/5 Best effort basis on event

Level-2 Cryosphere Science Requirements Summary (2/2)

Attribute	Permafrost Displacement (671)	Grounding Line Vertical Displacement (445)	Sea Ice Velocity (670)
Measurement	Spatially averaged relative velocities in two dimensions	Point-to-point relative displacements in two dimensions	Point-to-point relative horizontal displacements
Method	Interferometry	Interferometry	Backscatter image feature tracking
Duration	3 years	3 years	3 years
Product resolution	100 m	100 m	Gridded at 5 km
Accuracy	10 mm or better, over > 80% of coverage areas	100 mm or better, over 95% coverage areas annually over 50% coverage areas monthly	100 m / day, over 70% of coverage area
Sampling	In snow-free months sufficient to meet accuracy (semi-monthly)	Monthly	Every 3 days
Coverage	Targeted priority regions in Alaska and Canada	Greenland and Antarctic coastal zones	Seasonally-adjusted Arctic and Antarctic sea ice cover
Response latency	N/A	24 hour tasking, 5 hour data delivery Best effort basis on event	24/5 Best effort basis on event

Level-2 Ecosystem Science Requirements Summary

Attribute	Biomass (673)	Disturbance (675)	Inundation (677)	Crop Area (679)
Measurement	Biomass	Areal extent	Areal extent	Areal extent
Method	Polarimetric backscatter to biomass	Polarimetric backscatter temporal change	Polarimetric backscatter contrast	Polarimetric backscatter contrast and temporal change
Duration	3 years	3 years	3 years	3 years
Product resolution	100 m	100 m	100 m	100 m
Accuracy	20 Mg/ha or better where biomass is < 100 Mg/ha, over 80% of coverage areas	80% or better classification accuracy where canopy cover changes by > 50%	80% or better classification accuracy	80% or better classification accuracy
Sampling	Annual	Annual	Seasonal, sampled every 12 days to track beginning and end of flooding events	Quarterly; sampled every 12 days to track beginning and end of growing season
Coverage	Global areas of woody biomass	Global areas of woody biomass	Global inland and coastal wetlands	Global agricultural areas
Response latency	N/A	24/5 Best effort basis on event	24/5 Best effort basis on event	N/A

Benefits of both US-contributed L-band SAR and India-contributed S-band SAR

- *Global* L-band and *globally-distributed but targeted* S-band data with dense spatial and temporal sampling
  - extend the range of sensitivity for biomass estimation and surface deformation, and aid in estimating soil moisture, ionosphere mitigation
  - improve classification of natural surfaces, change detection
- S-band instrument has greater coverage capacity than current plan uses

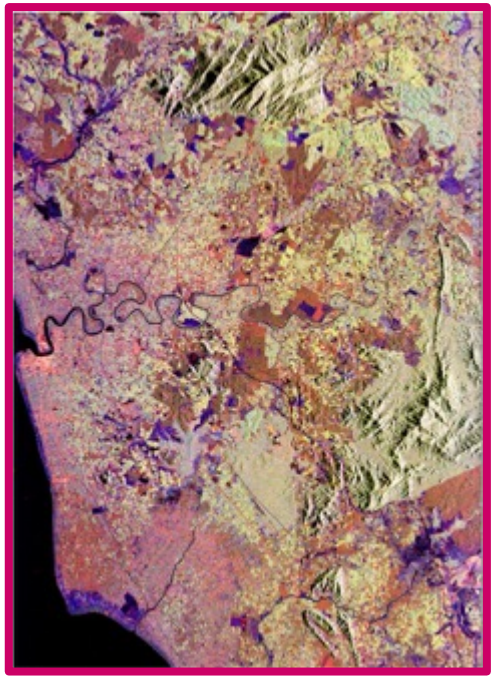
Wheat Fields,

Dnieper River, Ukraine

Red: LHH
Green: LHV
Blue: CHV

Rubber, banana, and oil palm trees,

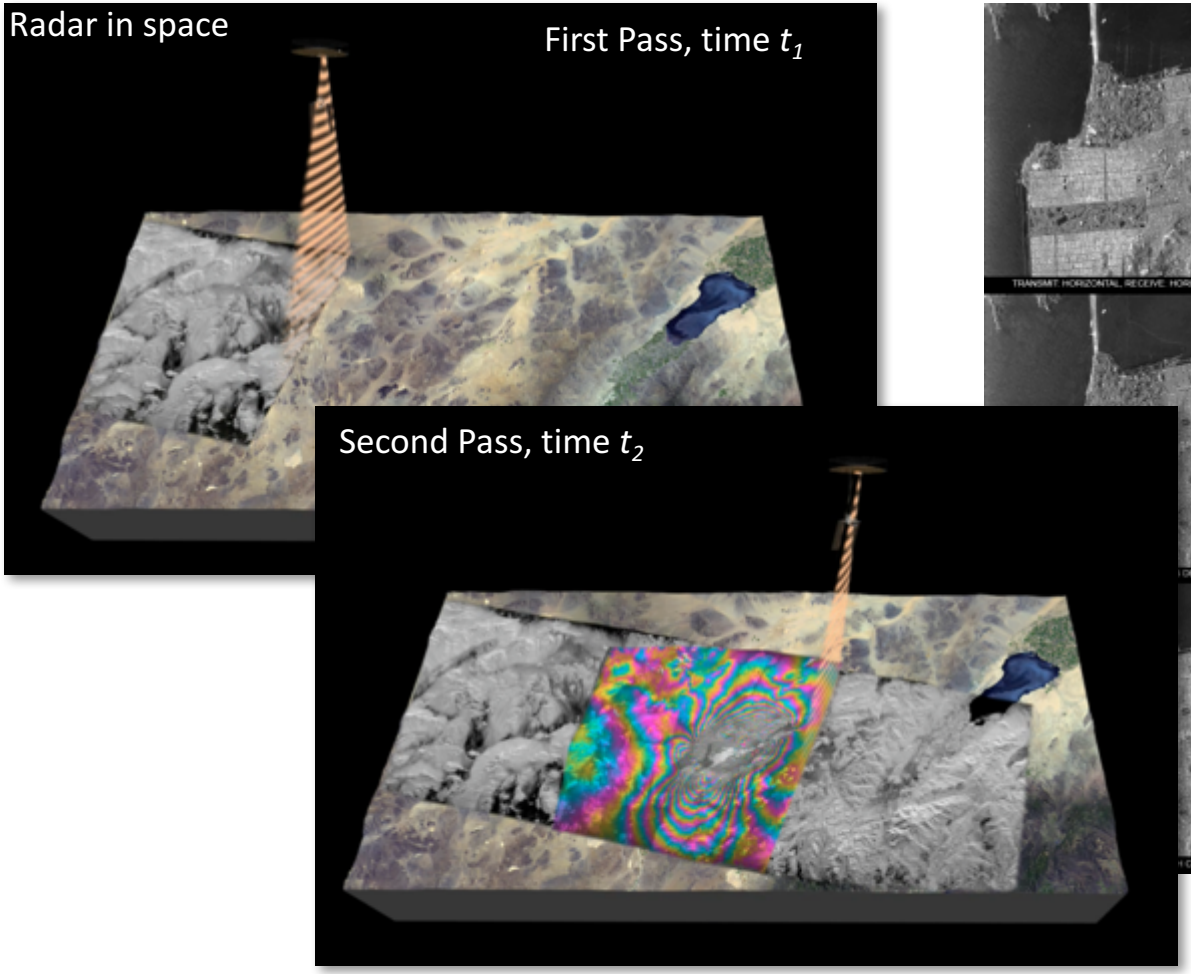
Muar, Malaysia



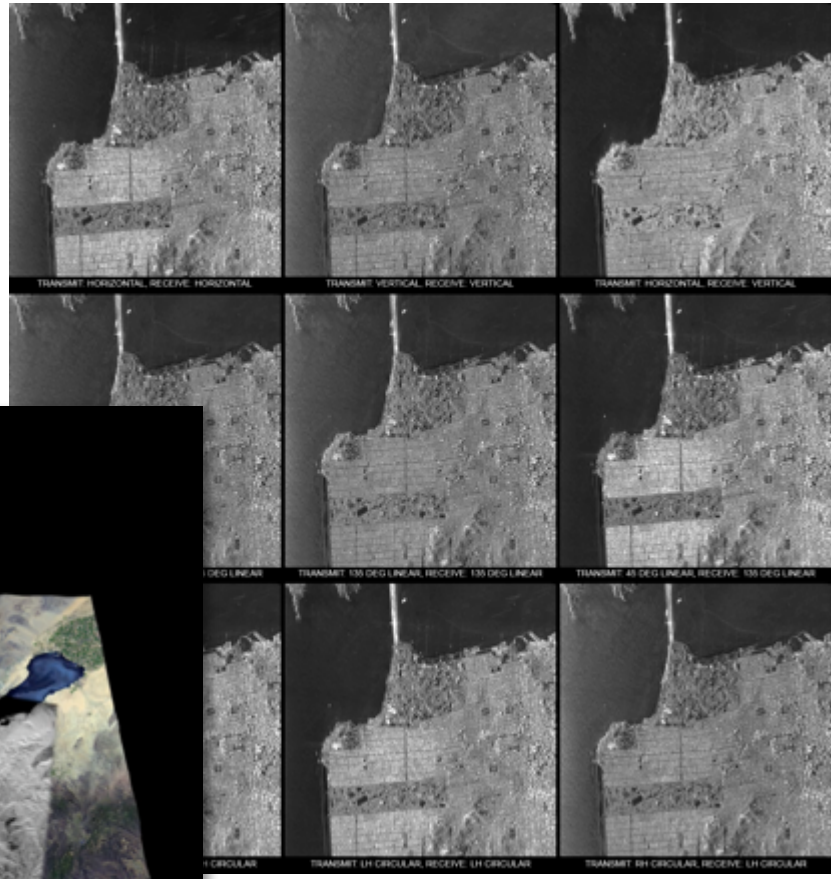
Examples of dual-frequency measurements from SIR-C/X-SAR

NISAR Measurements to Achieve Science Objectives

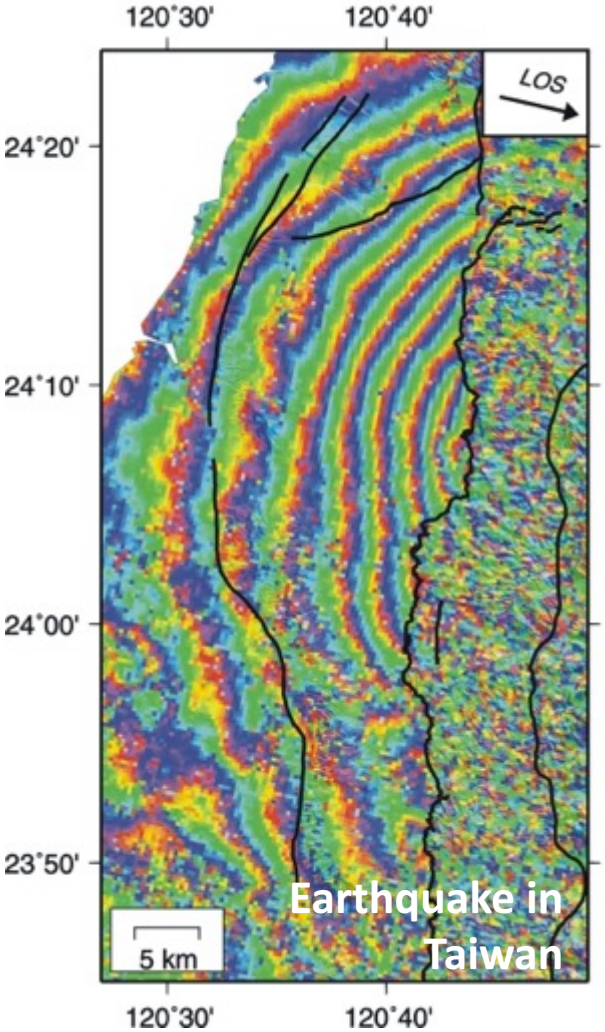
Repeat Pass Interferometry



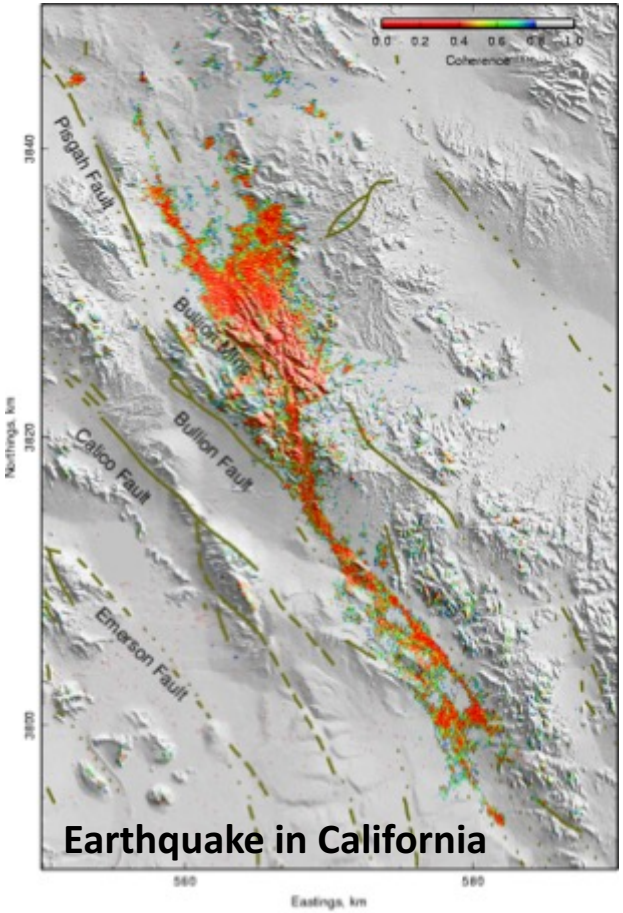
Polarimetric Diversity



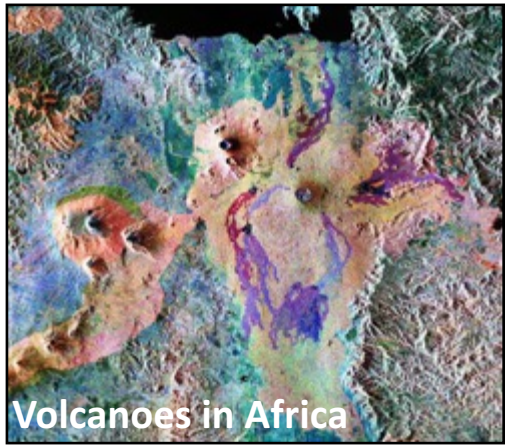
Basic Geodetic & Imaging Measurements

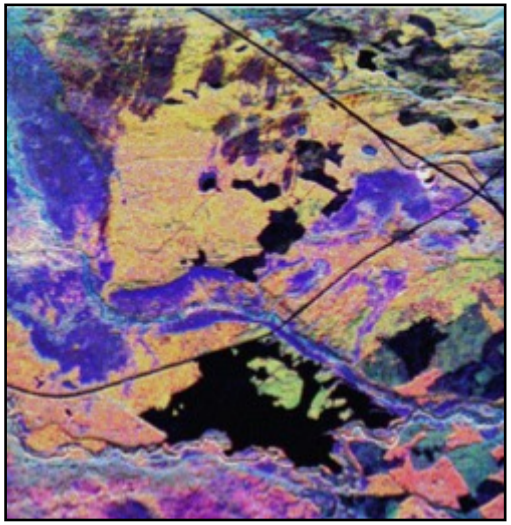


Interferogram – How much motion?



Decorrelation –
How severe the change?



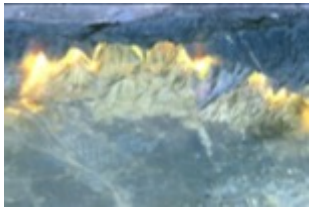


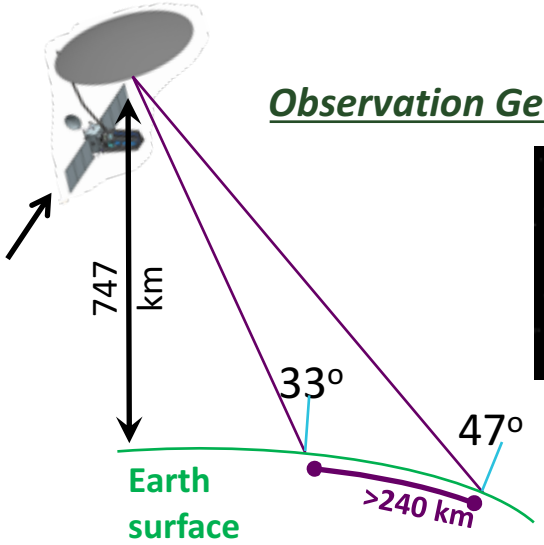
Polarimetry –
How much biomass?

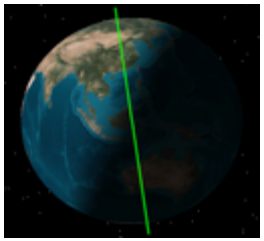
NISAR Concept Science Observation Overview

NISAR Characteristic:	Would Enable:
L-band (24 cm wavelength)	Low temporal decorrelation and foliage penetration
S-band (12 cm wavelength)	Sensitivity to light vegetation
SweepSAR technique with Imaging Swath > 240 km	Global data collection
Polarimetry (Single/Dual/Quad)	Surface characterization and biomass estimation
12-day exact repeat	Rapid Sampling
3 – 10 meters mode-dependent SAR resolution	Small-scale observations
3 years science operations (5 years consumables)	Time-series analysis
Pointing control < 273 arcseconds	Deformation interferometry
Orbit control < 500 meters	Deformation interferometry
> 30% observation duty cycle	Complete land/ice coverage
Left/Right pointing capability	Polar coverage, north and south

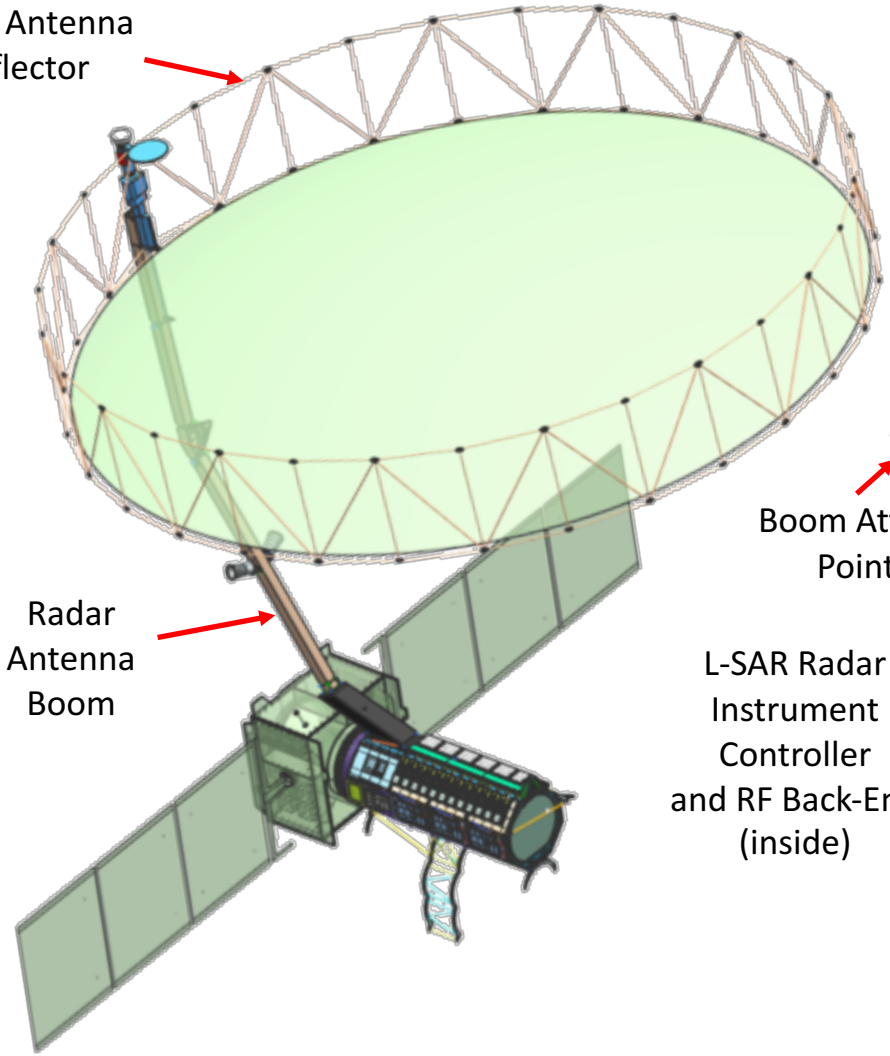
NISAR Will Uniquely Capture the Earth in Motion





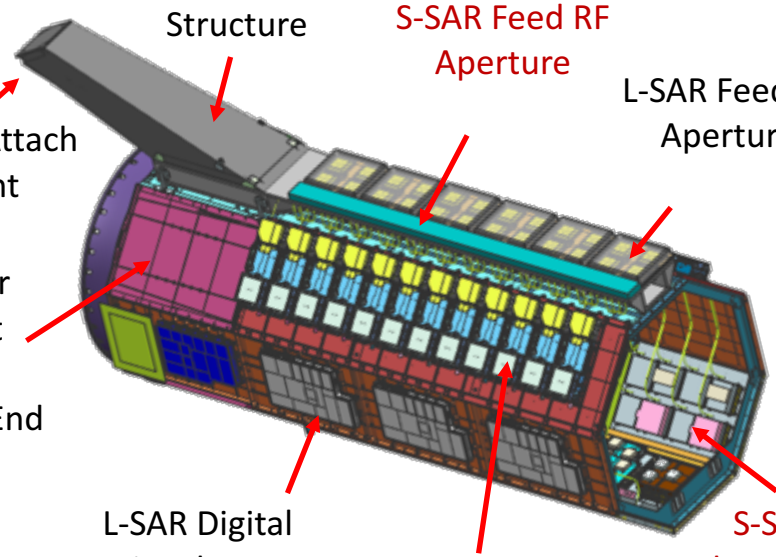


NISAR Instrument Overview



Instrument Subsystems:

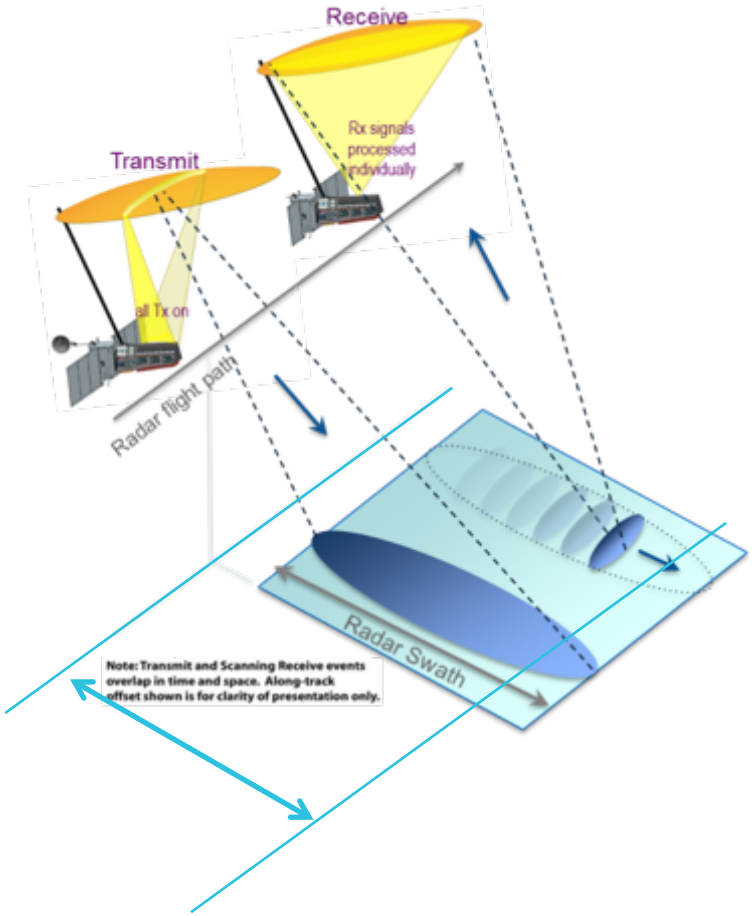
- L-Band SAR (JPL)
- S-Band SAR (ISRO)
- Instrument Structure (JPL)
- Radar Antenna (JPL)



Instrument Structure also houses GPS unit and Solid State Recorder

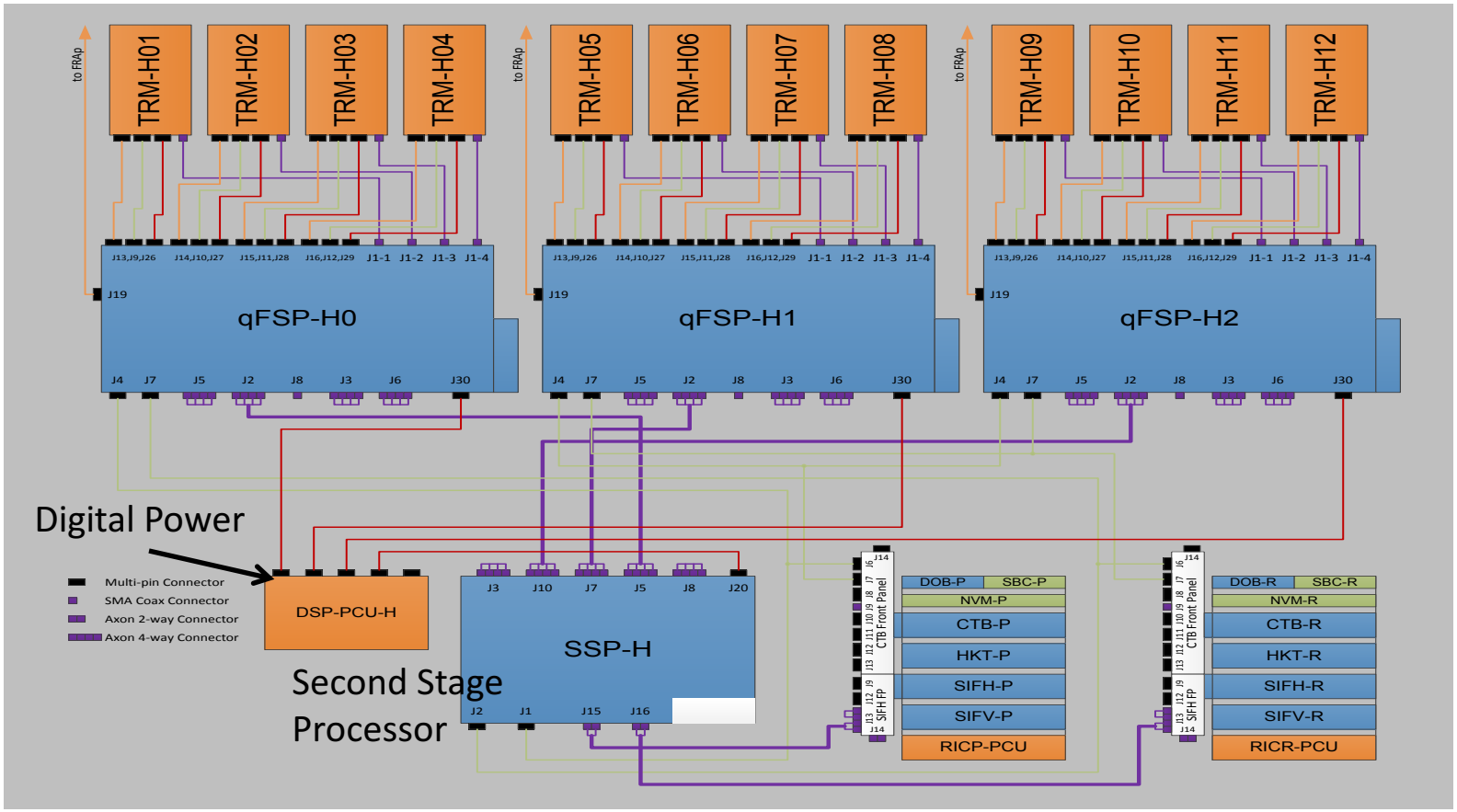
NISAR Swath Coverage

- All science disciplines require frequent coverage over global targets
- NISAR approach would acquire sufficient swath to cover equatorial ground track extent
  - ➔ Global access at desired time sampling and imaging characteristics
- *SweepSAR* technology being implemented independently by both JPL and ISRO
  - Transmit pulse with full feed illumination
  - Track echo digitally with individual receivers (12 at L-band; 24 at S-band)
  - Assemble individual receivers into a full-swath measurement



~236 km Earth-fixed ground track spacing at equator for 12-day repeat orbit

L-SAR Electronics
(Only Horizontal Polarization Shown)



Transmit Receive Modules

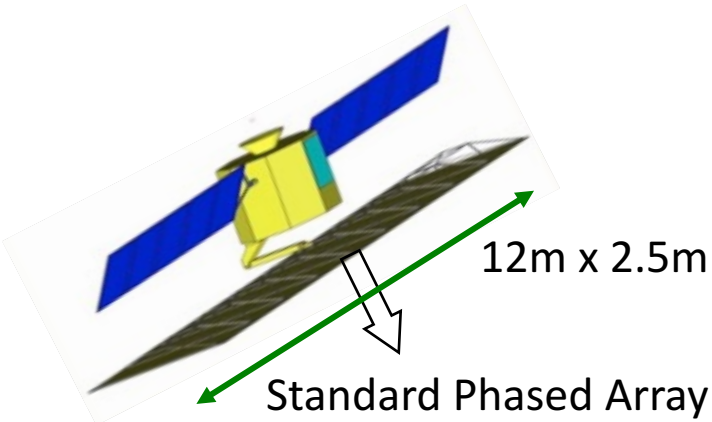
First Stage Processors

System Timing, Telemetry, Solid State Recorder Interface

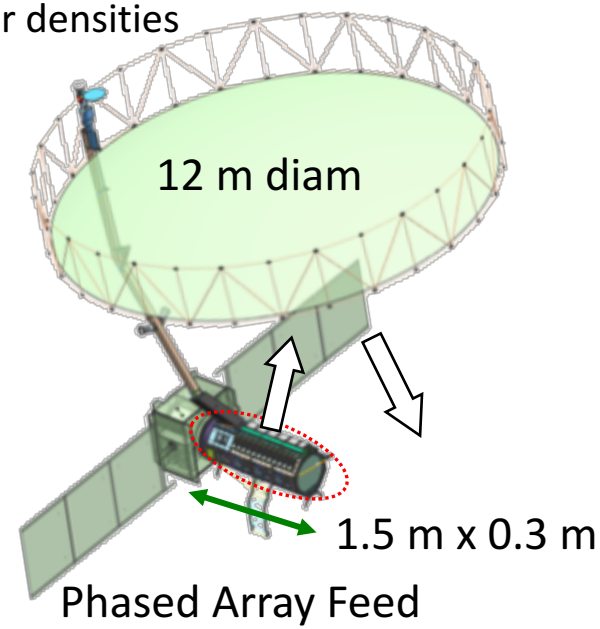
High Power Density Phased Arrays

- The SweepSAR reflector architecture is expected to be more cost effective than a traditional phased array, but the RF and DC power densities become much higher

- Development focused on improving reliability for high power densities
  - Increase RF power density
  - Improve component stability
  - Enable new instrument architecture



For 2kW RF Peak Radiated Power



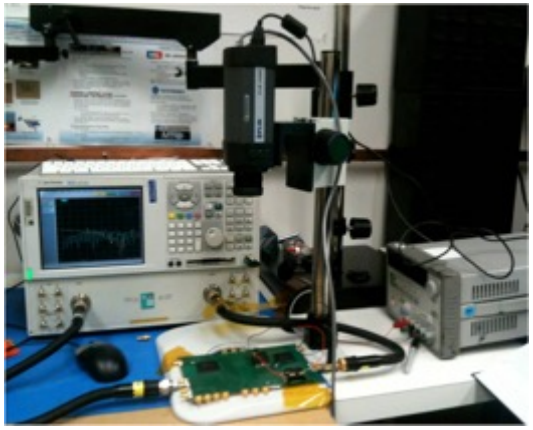
- Lower RF Power Density (67 W/m^2)
- Larger Radiator Area (30 m^2)
- Higher Thermal Inertia

- Higher RF Power Density (4000 W/m^2)
- Smaller Radiator Area (0.5 m^2)
- Lower Thermal Inertia

GaN High Power Amplifier for L-SAR

Increased RF output, decreased DC power and heat

- Exhaustive studies of GaN-based high-power amplifiers showed that NISAR could decrease its DC power by almost half of a kilowatt by moving from then-state-of-art Bipolar devices to GaN
- DC power savings are matched by a decrease in waste heat
- JPL tested devices from multiple vendors for TID (total dose) and SEE (Single Event Effects)
  - All devices tested showed no ill-effects from radiation, up to our required levels
  - L-SAR now has 24 GaN High Power Amplifiers



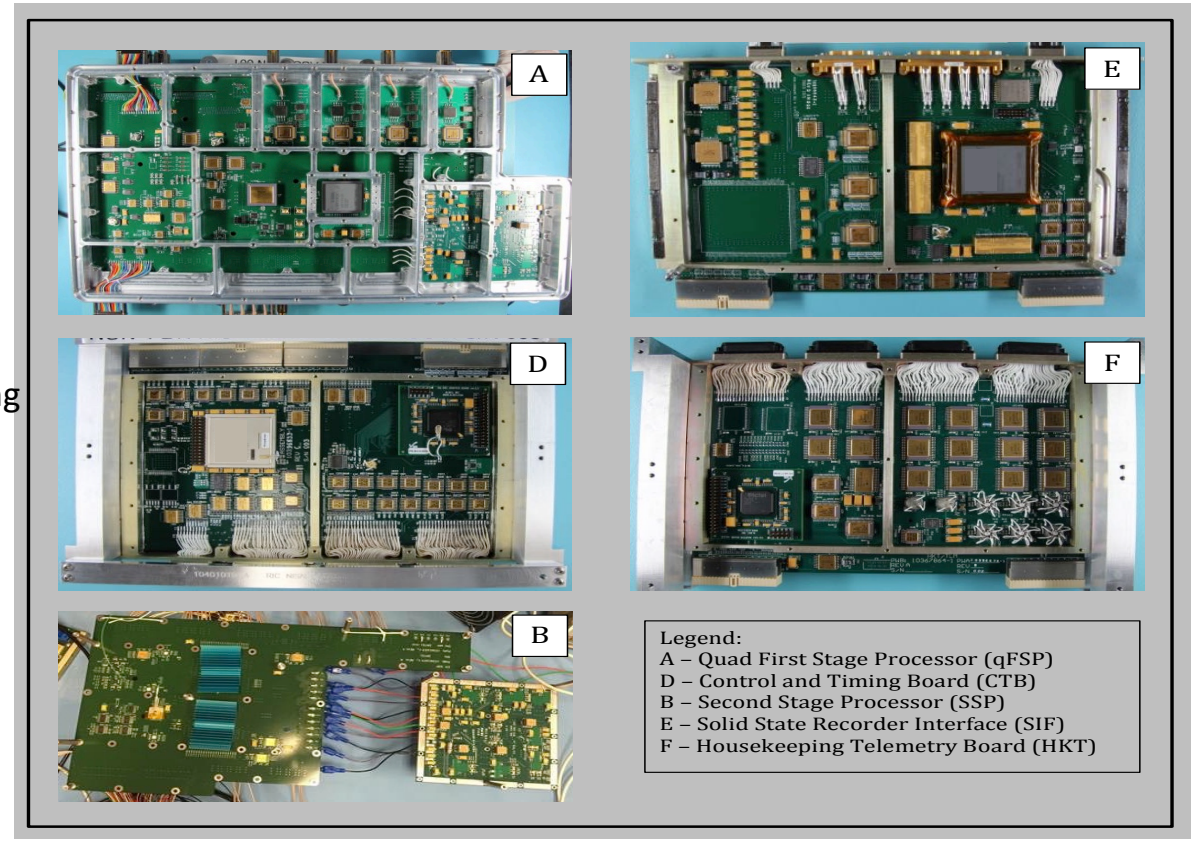
- Tested with FLIR thermal camera (left) and thermal chamber
- Devices shown to not exceed NASA standards for device temperature
- Transmitters shown to be thermally stable

L-SAR Digital Hardware

qFSP (quad First Stage Processor): Controls TRM, digitizes RF, digital calibration, preliminary beamforming

CTB (Control and Timing Board): System timing/Command distribution

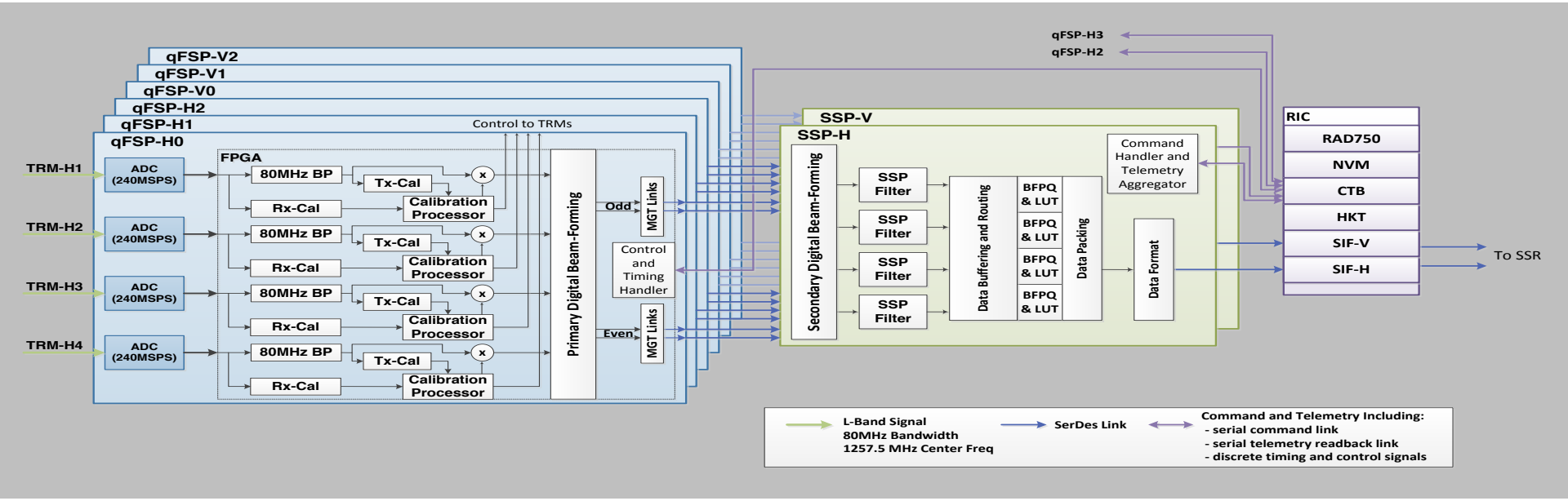
SSP (2nd Stage Processor): DBF, data packing, formatting, headers



SIF (Solid State Recorder Interface): Formats data for recorder, adds telemetry headers

HKT (House-Keeping & Telemetry): Monitors instrument temperature and voltages for health and for calibration.

L-SAR Digital System Data Flow
Both H and V Polarizations Shown



L-band RF Signals IN

240 MHz Samples

Dig. Filtering/ Rx Cal

Tx Cal

Cal Correction

1st Stage Beamforming

To 2nd stage

2nd Stage Beamforming

Final Filtering

BFPQ & Lookup Table Corrections

Data Packing, Formatting, Headers

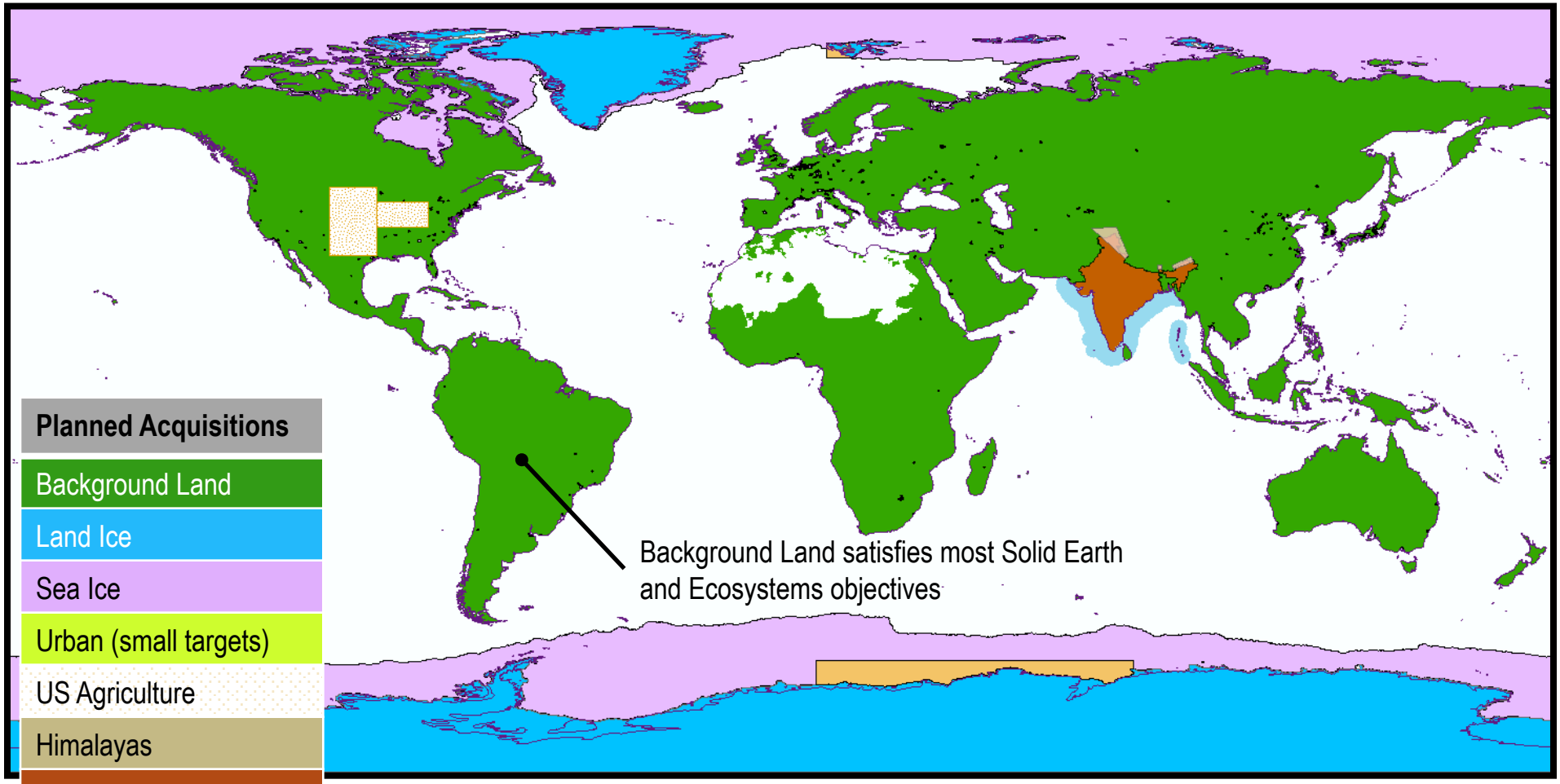
To Solid State Recorder

NISAR Science Observing/Operations Modes
Blanket Land and Ice Coverage Every 12 Days

- Observation strategy employs a small subset of possible modes

Observation Strategy	L-band		S-band		Culling Approach	
Science Target	**Mode+**	**Resolution**	**Mode**	**Resol.**	Sampling	Desc Asc
Background Land	DP HH/HV	12 m x 8 m			cull by lat	
Land Ice	SP HH	3 m x 8 m			cull by lat	
Sea Ice Dynamics	SP VV	48 m x 8 m			s = 1 p	
Urban Areas		6 m x 8 m			s = 1 p	
US Agriculture	QP HH/HV VV/VH				s = 1 p	
Himalayas			CP RH/RV		s = 1 p	
India Agriculture					s = 1 p	
India Coastal Ocean			DP HH/HV or VV/VH		s = 1 p	
Sea Ice Types	DP VV/VH				s = 3 p	

NISAR
Mode-Specific Science Targets in Observation Plan



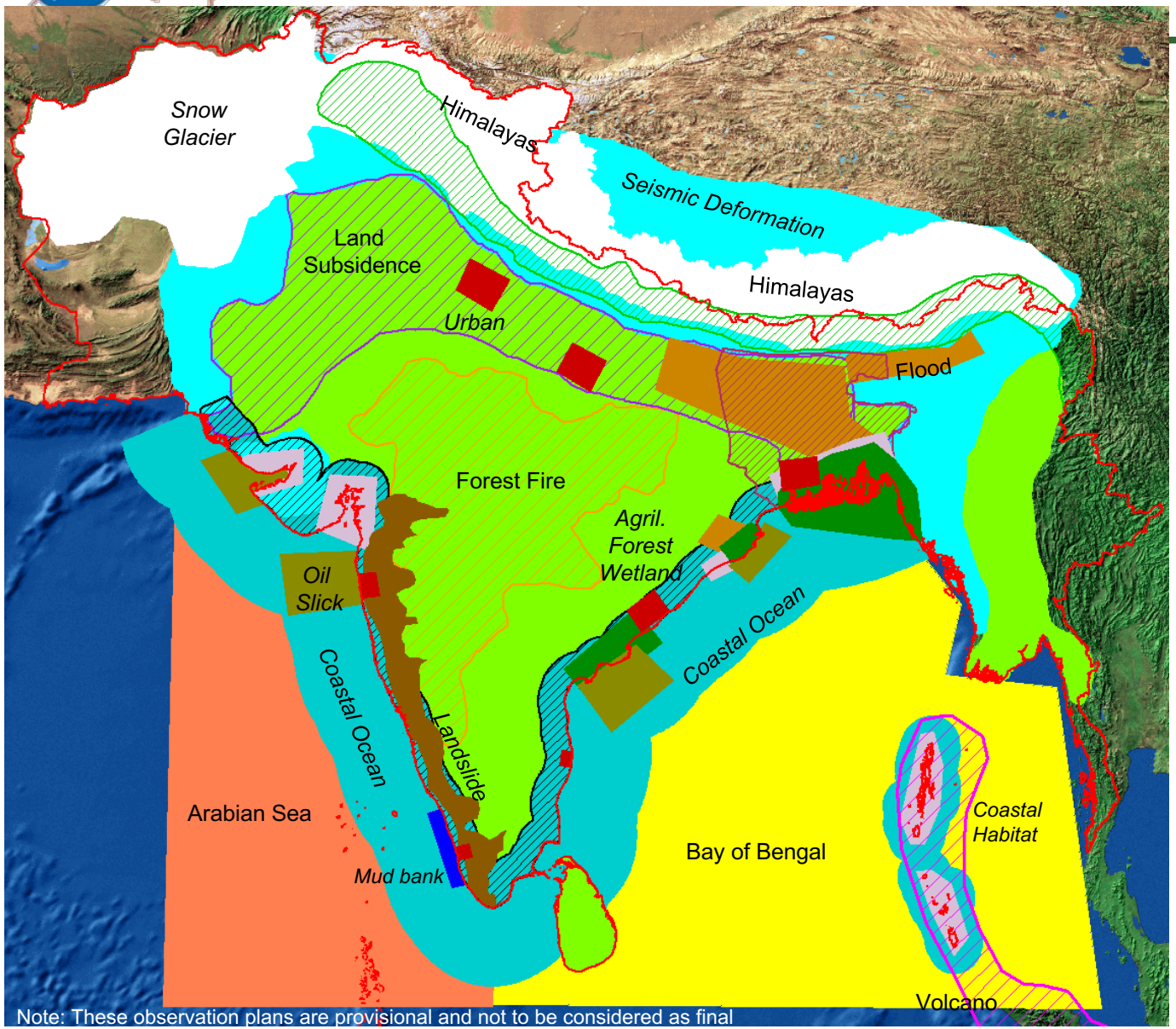
Planned Acquisitions

- Background Land
- Land Ice
- Sea Ice
- Urban (small targets)
- US Agriculture
- Himalayas
- India Agriculture
- India Coastal Ocean
- Sea Ice Type

- Each colored region represents a single radar mode chosen to satisfy multiple science objectives over that area
- Avoids mode contention that would interrupt time series

ISRO Targets over India and Surroundings

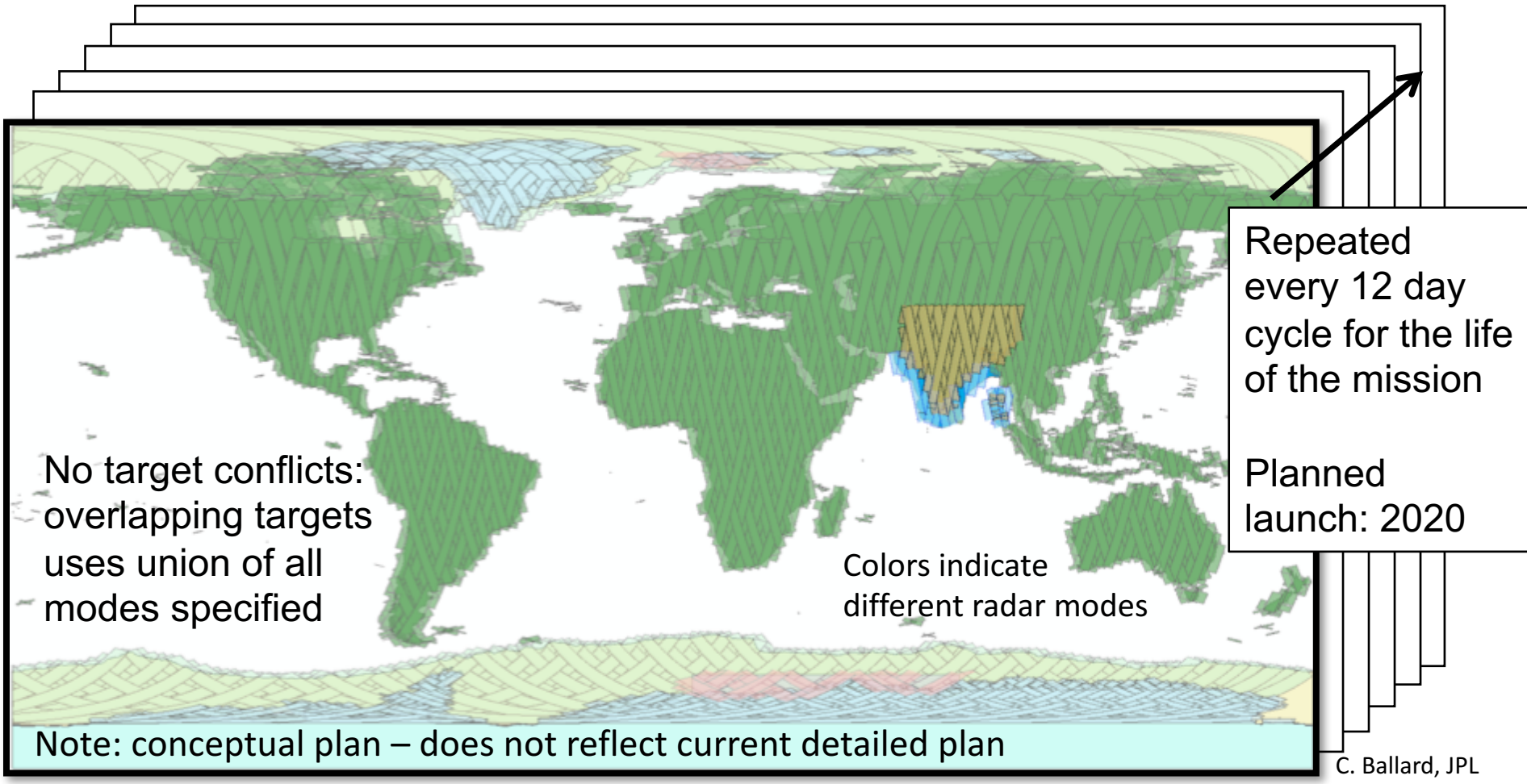
Additional polar targets augment NASA coverage



- India + neighbors boundary
- Agriculture/ Forest/ wetland
- Jute crop
- Alpine forest
- Seismic Deformation
- Land Subsidence
- Landslide
- Urban subsidence
- Volcanic deformation/ studies
- Coastal region (sea 300km)
- Coastal habitat
- Coastal deformation
- Coastal mud bank
- Coastal region (land, 100 km)
- Ocean – Arabian Sea
- Ocean – Bay of Bengal
- Disaster – floods
- Disaster – forest fire
- Disaster – oil slick
- Cryosphere - Himalayas

Note: These observation plans are provisional and not to be considered as final

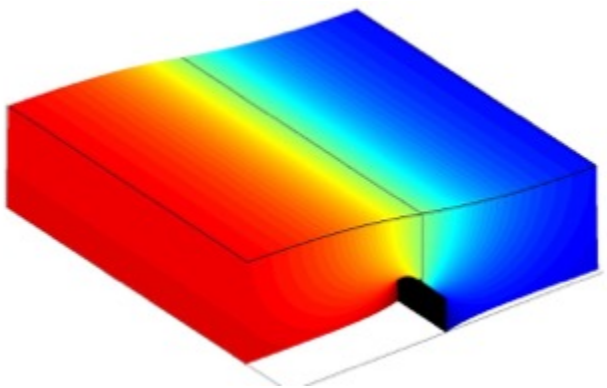
NISAR Systematic Observations
L-band globally – S-band over India

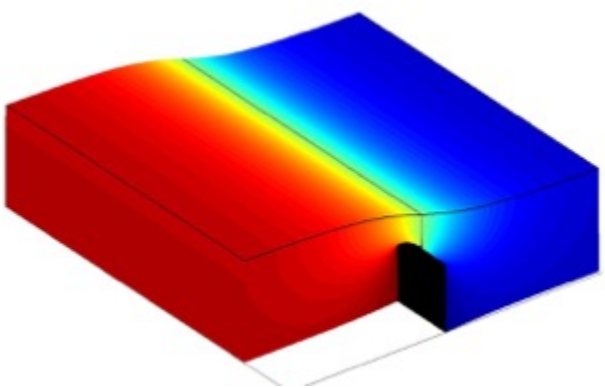


C. Ballard, JPL

Persistent updated measurements of Earth

Why measure deformation over the earthquake cycle?



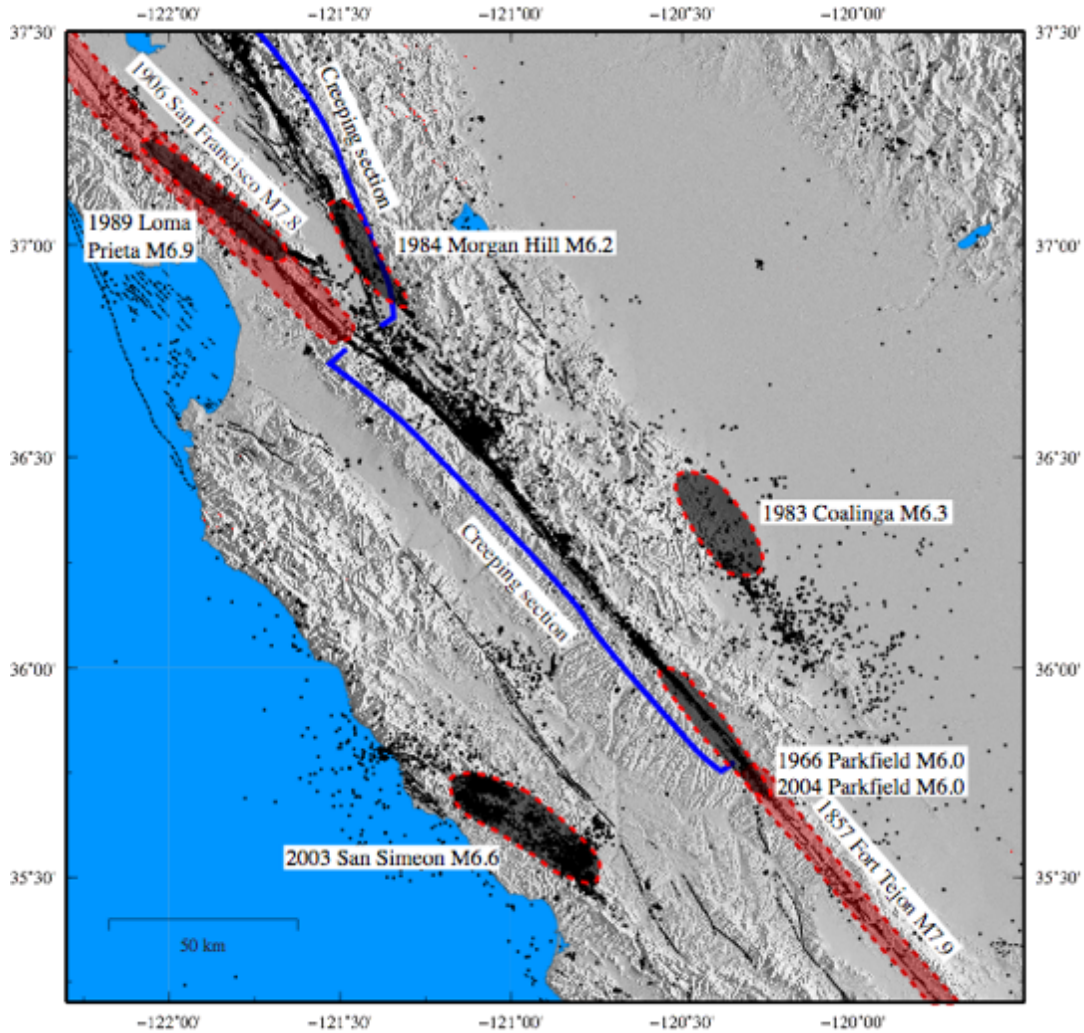


- Locate faults accumulating stress
- The magnitude of an earthquake depends on area that slips
- Locked region depends on the mechanical properties of the crust
- Ideally, measure time-dependent 3D motion

Mark Simons, Caltech

Seismotectonic Setting

Creeping section of the San Andreas Fault



150 km-long creeping section in between historic M7.8 earthquake rupture traces

Strong micro-seismic activity along the creeping sections (M<4 2006-2010)

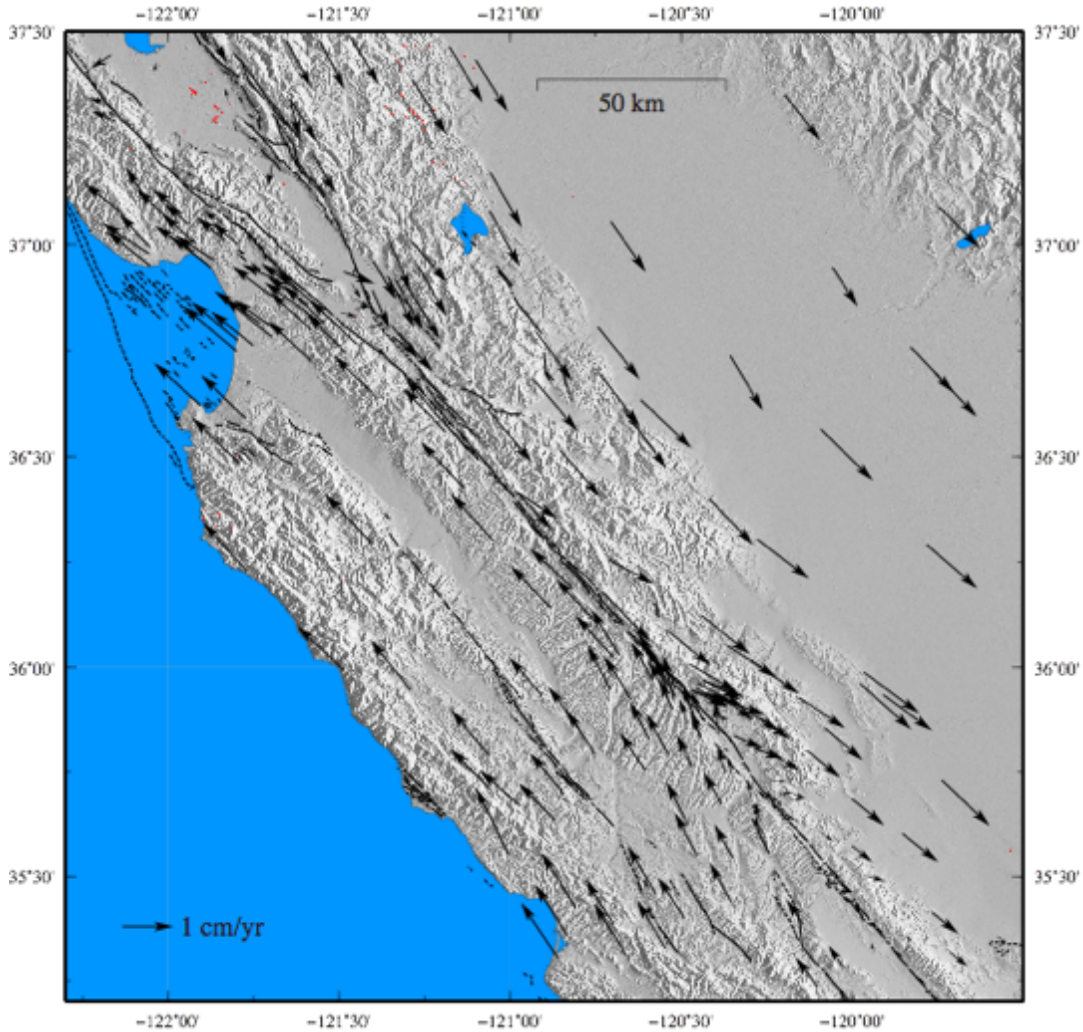
Several moderate size (M6+) regional earthquakes

Slip Deficit Buildup rate?
Variability along strike?

Mark Simons, Caltech

Seismotectonic Setting

Creeping section of the San Andreas Fault



No net rotation, Ref south SF bay

GPS velocity field

United Western US Crustal Motion Map
(Z.-K. Shen)

114 GPS sites: 1993 - 2011

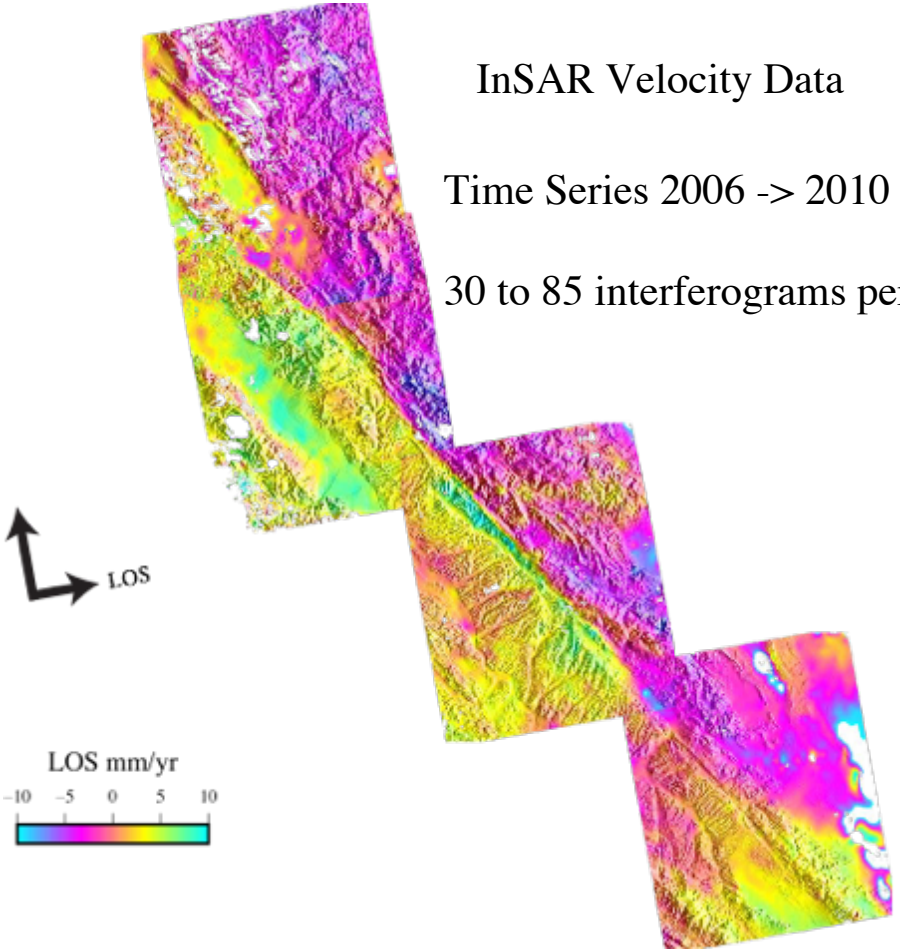
Mark Simons, Caltech

Measurements and Posterior Mean Model

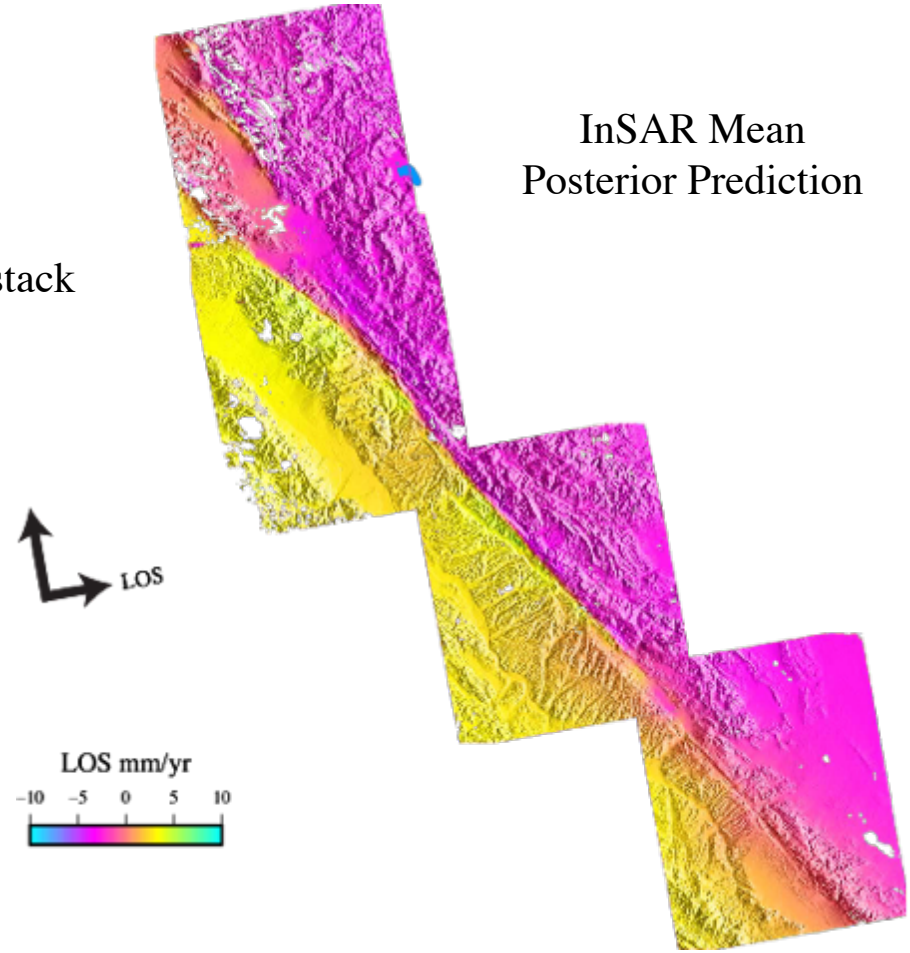
InSAR Velocity Data

Time Series 2006 -> 2010

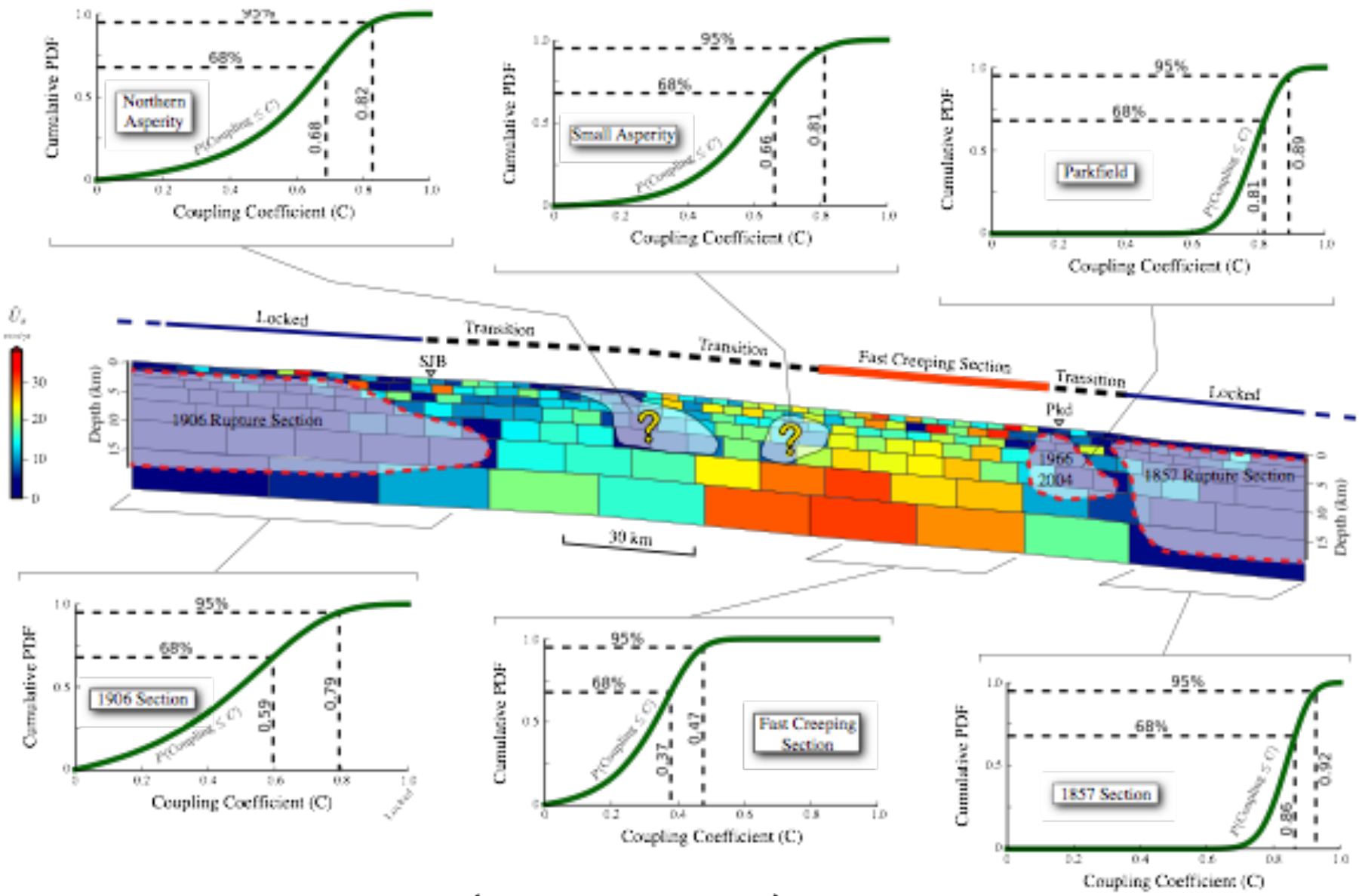
30 to 85 interferograms per stack



InSAR Mean Posterior Prediction



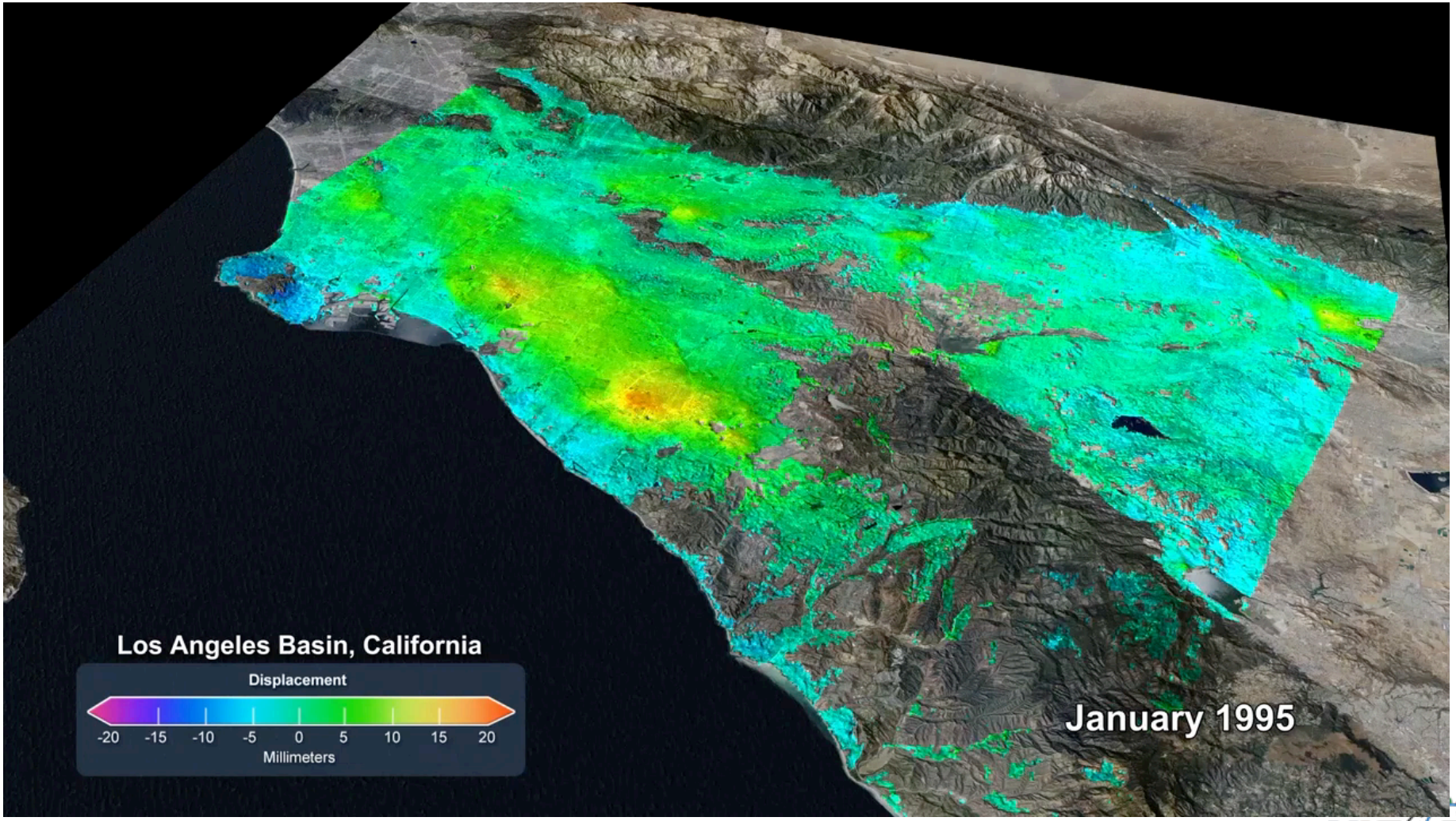
Mark Simons, Caltech



$$\mathrm{P(Coupling)} \leq C$$

Mark Simons, Caltech

LA Aquifer Utilization - Seasonal Component



Jet Propulsion Laboratory
California Institute of Technology

Ecosystem Monitoring with Time Series

Time Steps
0 2006-12-04
1 2007-01-19
2 2007-03-06
3 2007-07-22
4 2007-10-22
5 2008-01-22
6 2008-03-08
7 2008-04-23
8 2008-06-08
9 2008-07-24
10 2008-09-08
11 2008-10-24
12 2009-01-24
13 2009-03-11
14 2009-07-27
15 2009-09-11
16 2009-10-27
17 2010-03-14
18 2010-04-29
19 2010-06-14
20 2010-07-30
21 2010-09-14
22 2010-12-15
23 2011-01-30
24 2011-03-17

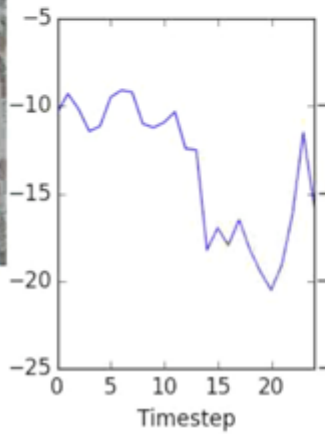
L-Band HH Backscatter

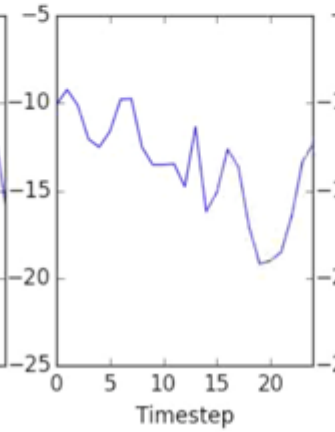
R=2006-12-04 G=2011-03-17 B=2011-03-17

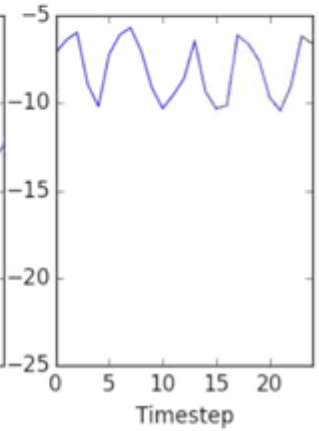
Deforestation

Degradation

Riparian Forest







Cerrado Area, Brazil
ALOS PALSAR DATA from 2006 to 2011

Abrupt drop in Backscatter

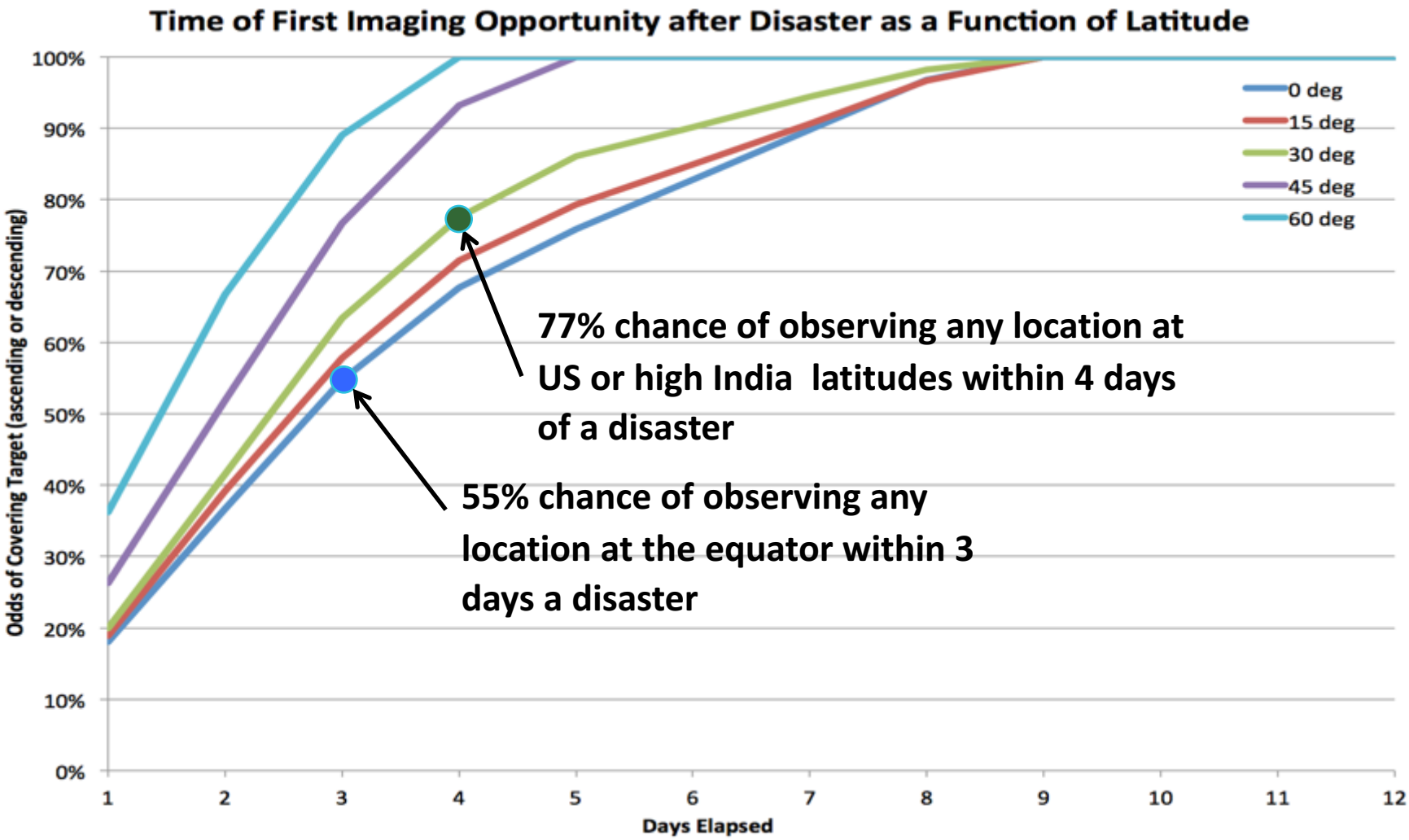
Gradual drop in Backscatter

Periodic patterns from seasonal flooding

Societal Challenges and What SAR Can Contribute

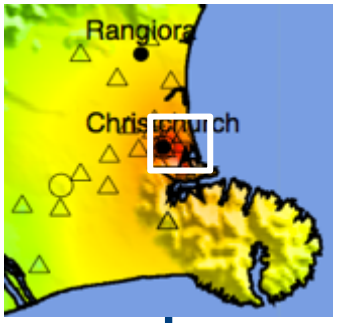
Challenge	Benefit Through Regular SAR Monitoring of:
Global Food Security	- Soil moisture and crop growth at agricultural scale - Desertification at regional scales
Freshwater Availability	- Aquifer use/extent regionally - Water-body extent changes - Glaciers serving as water sources
Human Health	- Moisture and vegetation as proxy for disease and infestation vectors
Disaster Prediction & Hazard Response	- Regional building damage and change assessment after earthquakes - Earthen dams and levees prone to weakening - Volcanoes, floods, fires, landslides
Climate Risks and Adaptation	- Ice sheet/sea-ice dynamics; response to climate change - Coastal erosion and shoreline migration
Urban Management and Planning	- Urban growth through coherent change detection - Building deformation and urban subsidence
Human-activity Based Climate Change	- Deforestation's influence on carbon flux - Oil and gas reservoirs

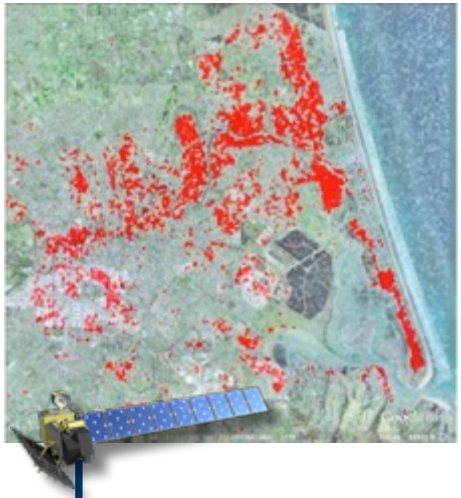
NISAR Mission Concept
Rapid Response Time-to-Image



NISAR Mission Can Improve Disaster Response

Damage Proxy Map from radar data





Shakemap released by USGS NEIC

Radar data acquired by ALOS satellite

Official damage map released based on ground observations

Official damage map updated based on ground observations

2011 | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct

M6.3 Christchurch Earthquake

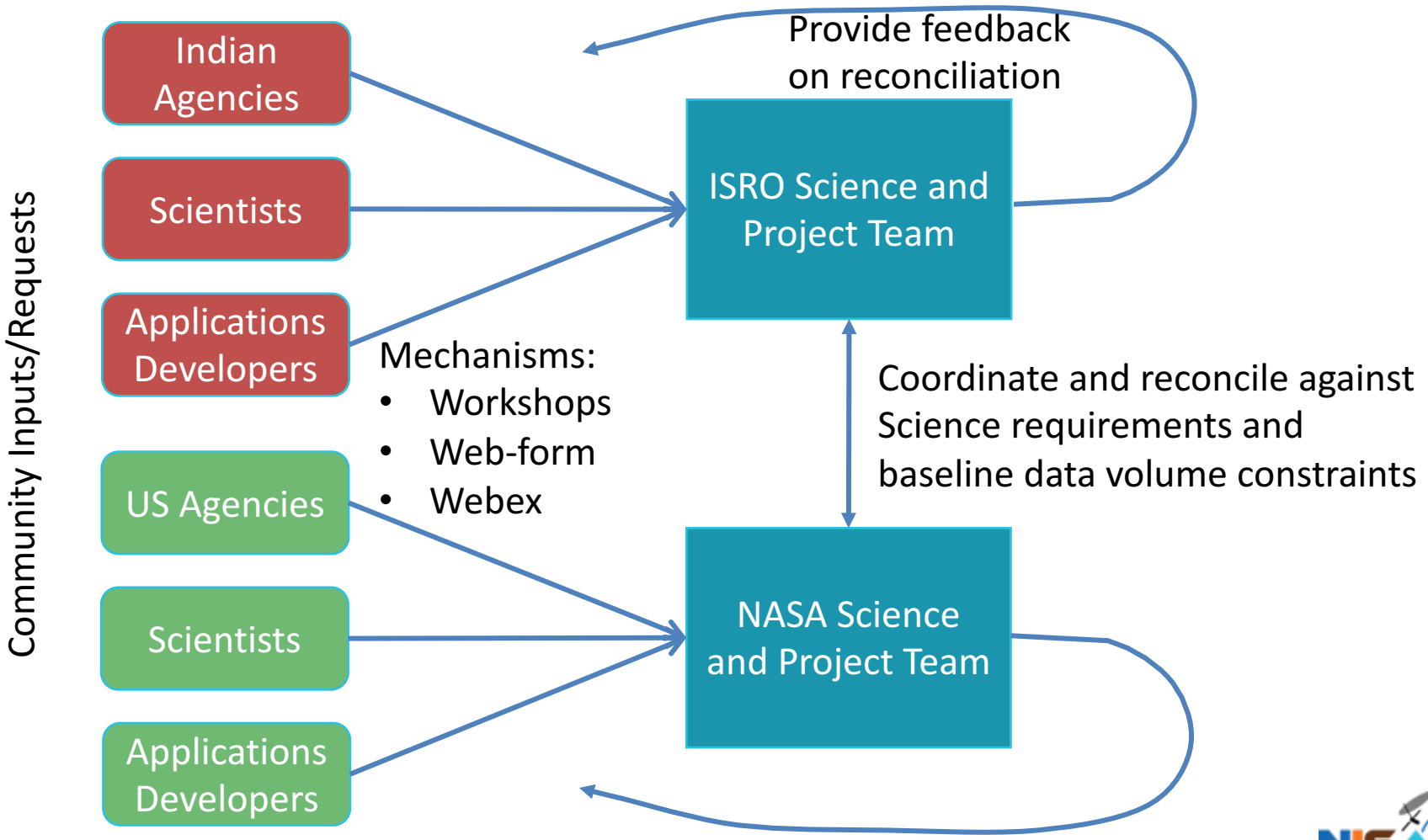
- 185 people killed
- > 1000 buildings destroyed
- Over US $30 billion damage

Original ALOS Data © JAXA, METI 2011

Official damage map provided by the New Zealand Government (http://data.govt.nz)

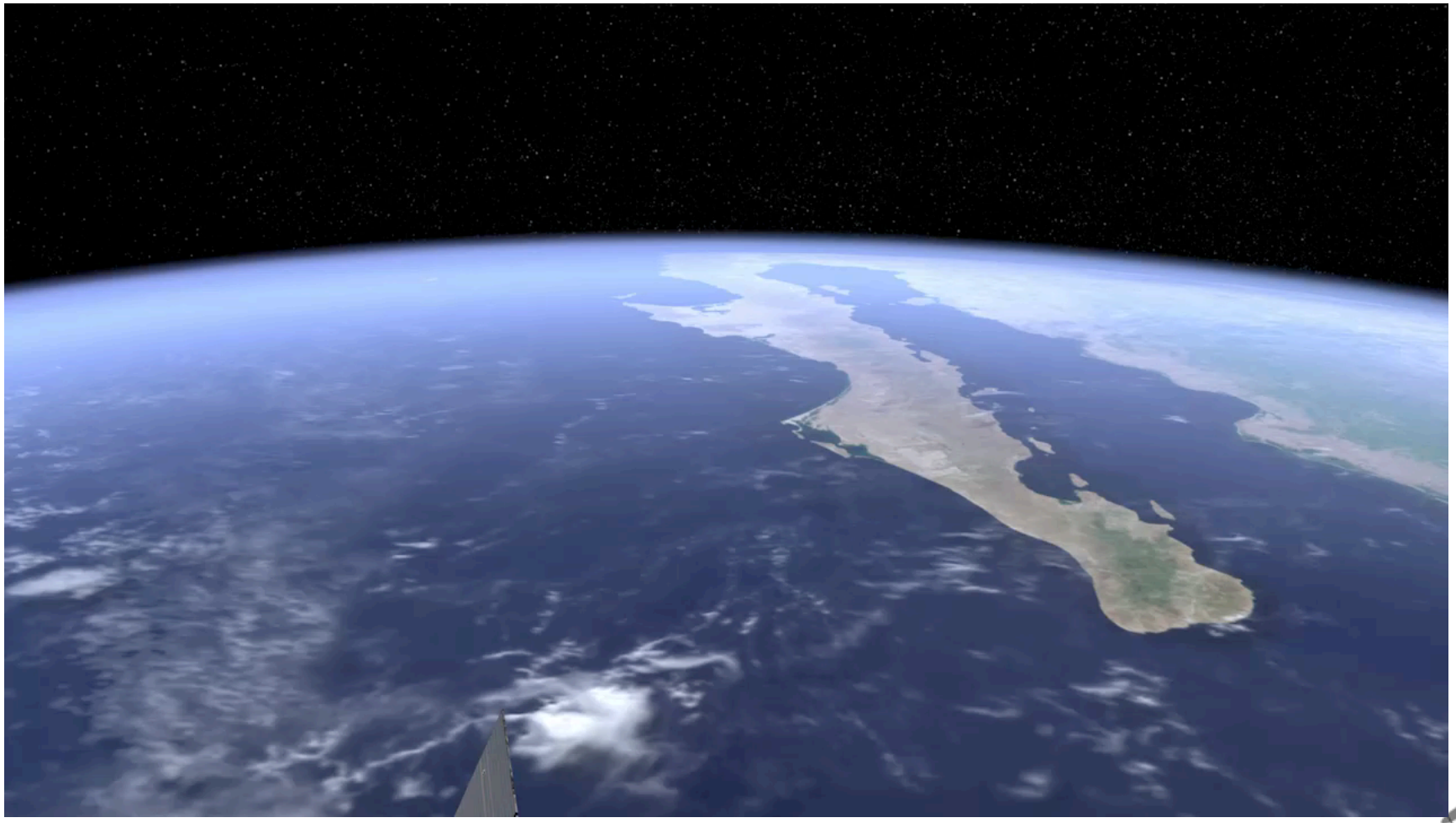
Community Input to the Science Observation Plan

- Periodically (every six months) during development and operations:



Summary

- NISAR will deliver global data sets at L-band and targeted data sets at S-band for global-scale science
- Systematic monitoring capability allows understanding of time-variable processes with dense sampling and wide coverage
- Science data acquired in this consistent way have strong potential for societal benefits, in terms of reliability of coverage, response time, and quality of data sets
- Dual-frequency measurements will be a new resource for understanding Earth over large areas
- Observation planning process accepts community input to optimize science

Status

- NISAR is currently in Development Phase C