The NISAR Mission – An NASA/ISRO Space Partnership Supporting Global Research and Applications

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New Delhi, India

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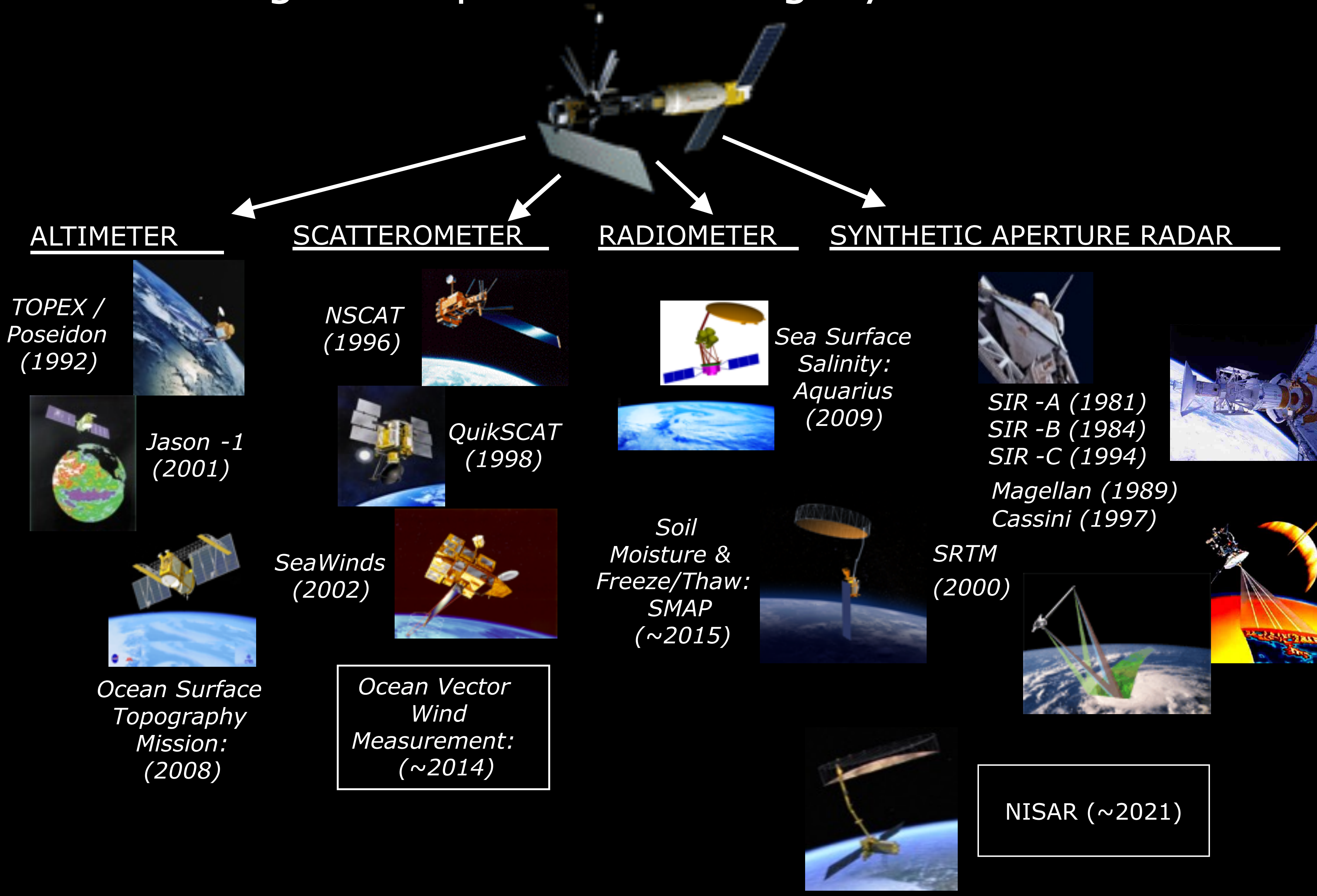
Outline of Talk

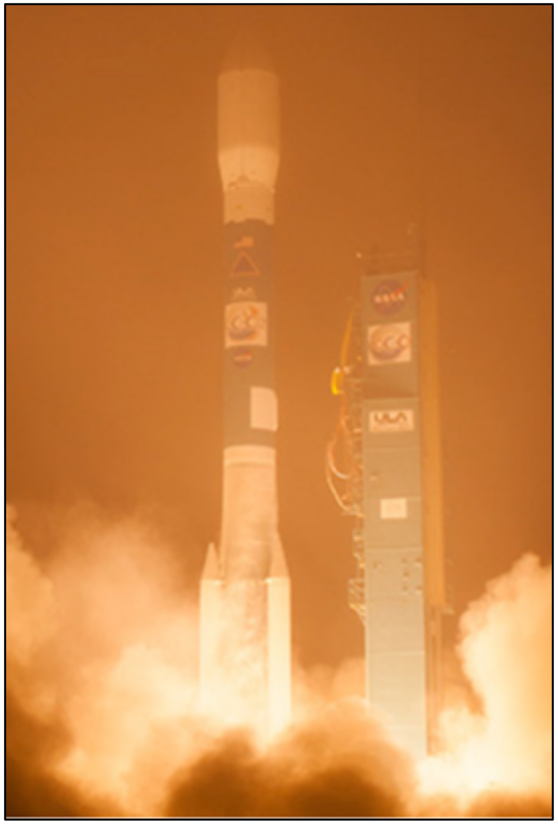
- Background on NASA/JPL Science Missions
- The NASA ISRO SAR Mission
  - Science Requirements
  - Technology Approach
  - Observation Plan
- Science and Applications Examples

Grail
Sep 2011
Moon Gravity
Juno
August 2011
Jupiter
NuSTAR
June 2012
High Energy X-ray
Mars Science Lab
August 2012
Curiosity Rover
Aquarius/SAC-D
June 2011
Sea Salinity
Gallery of JPL Missions
Also:
Kepler 2009
Galex 2003
Herschel 2009
MMM 2008
Diviner 2009
Explorer 1-5
1958
Van Allen Belts
Ulysses
Ulysses
1990
Solar Polar Orbit
Microwave Instrument
2004
Rosetta Comet Orbiter
MARSIS
2003
Deep Sounder
Spitzer Telescope
2003
Infrared Telescope
Seawinds
2002
Ocean Winds
Pioneer 3-4
1958
Lunar Flybys
Wide Field Camera
1990
Fix Hubble
Mars Rovers
2003
Rovers
Genesis
2001
Solar Wind
Samples
Rangers
1961-1965
Lunar Surveys
Topex/Poseiden
1992
Ocean Altimeter
Emission Spectrometer
2004
Infrared Sensor
Microwave Sounder
2004
Ozone
AIRS
2002
Infrared Sounder
AIRS
SRTM
2000
Earth Radar
Surveyors
1966-1968
Lunar Landers
Global Surveyor
1996
Mars Orbiter
Grace
2002
Earth Gravity
Deep Space 1
1998
Ion Engine
Mariner 1-2
1962
Venus Flybys
Cassini
1997
Saturn & Moons
Deep Impact
2005
Smash Comet
EPOXI
MRO
2005
SHARAD
Cloudsat
2006
Precipitation
Jason 1
2001
Ocean Altimetry
VLBI
1997
Astronomy
Mariner 3-4
1964
Mars Flybys
Pathfinder
1996
Mars Rover
Mariner 5
1967
Venus Flyby
Stardust
1999
Comet Wild-2
Quickscat
1999
Sea Winds
Radiometer
1999
Earth Thermal
Multi-Angle Spect
1999
Earth Imaging
Active Cavity
1999
Solar Radiance
Keck
2001
Astronomy
Mars Odyssey
2001
Mars Imaging
NSCAT
1996
Earth Winds
Mariner 6-7
1969
Mars Flybys
Mariner 8-9
1971
Mars Orbiter
Mariner 10
1973
Venus / Merc
Viking
1975
Mars Landers
Voyager
1977
Grand Tour
Seasat
1978
Earth Radar
Solar Explorer
1981
Earth Ozone
SIR A, B, C
1981, 84, 94
Earth Radar
Infrared Sat
1983
Telescope
Magellan
1989
Venus Radar
Galileo
1989
Jupiter
Mars Observer
1992
Mars Orbiter

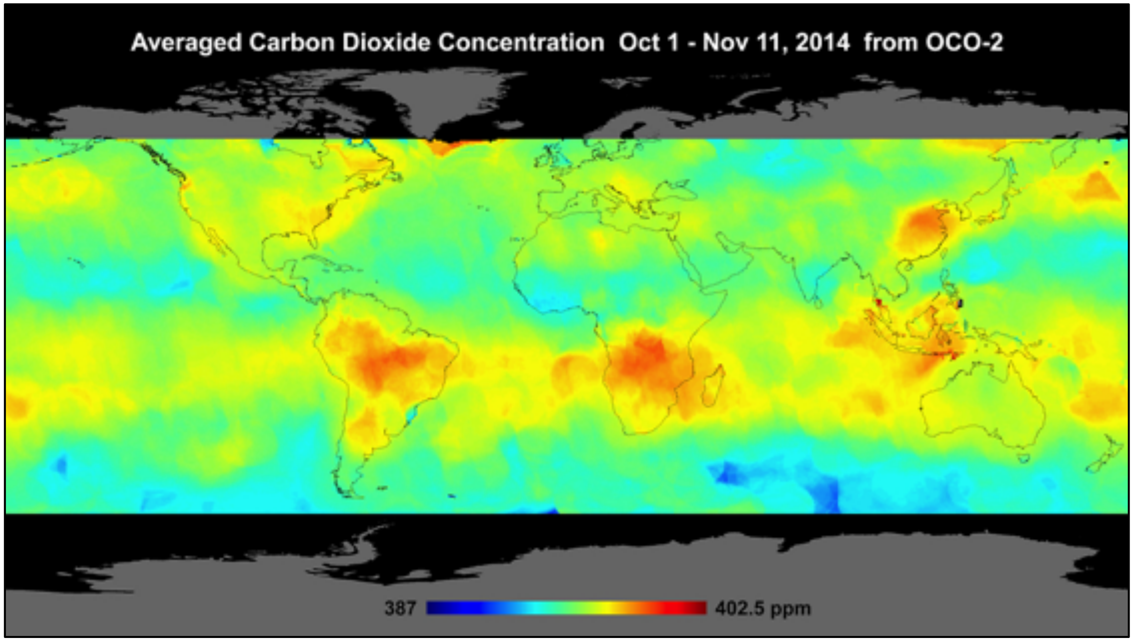
How it began in Space … The Legacy of SeaSat



OCO-2: Making Monthly Maps of Carbon Dioxide



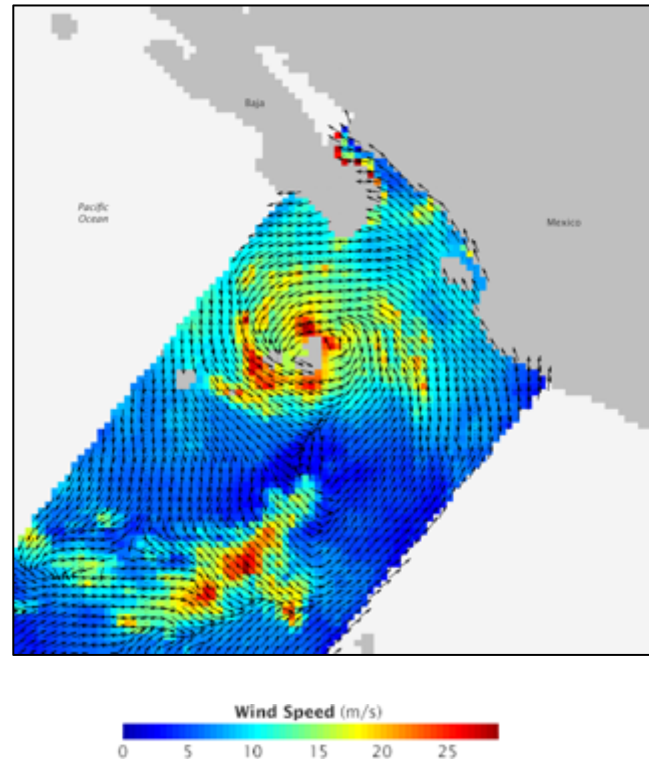
Launch: July 2, 2014



First Global Map: December 18, 2014

RapidScat: Making Daily Maps of Winds over the Ocean

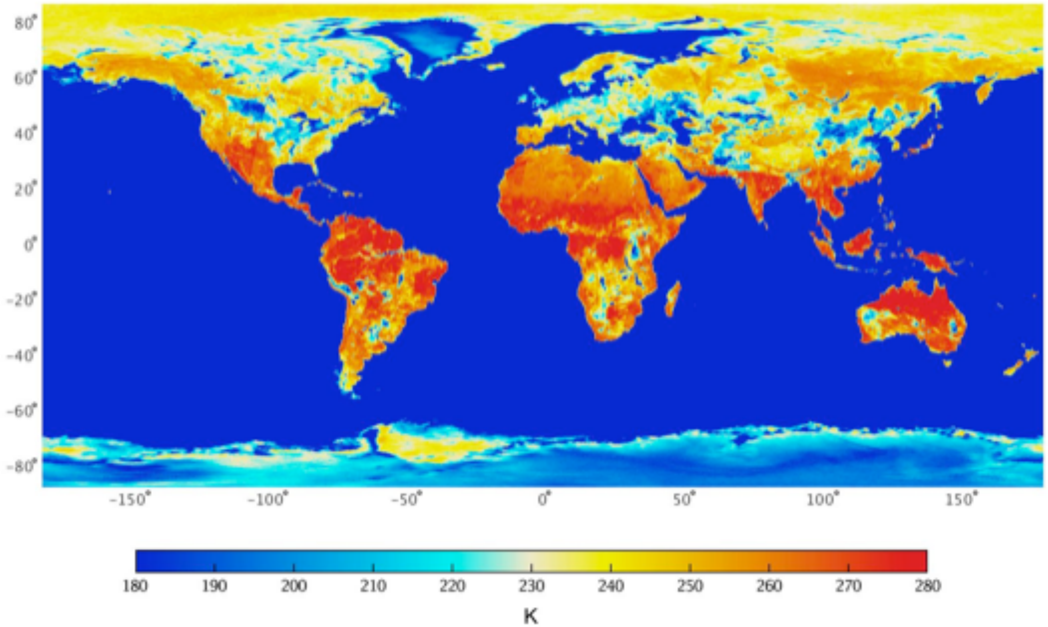
Installation on International Space Station: September 30, 2014



First Light: October 3

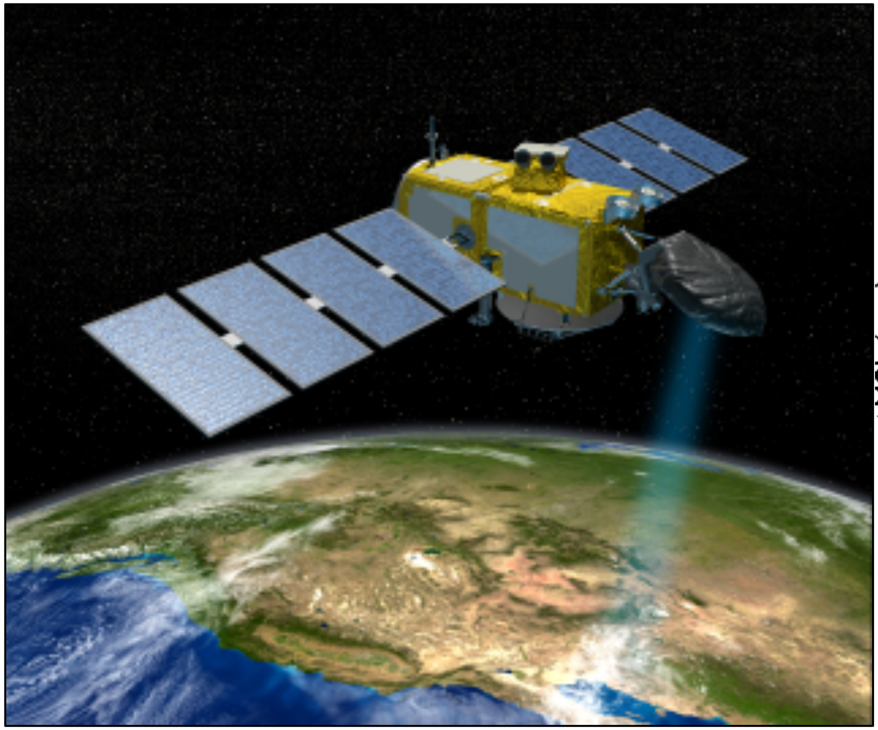
SMAP: Measuring Soil Moisture Globally every 3 Days

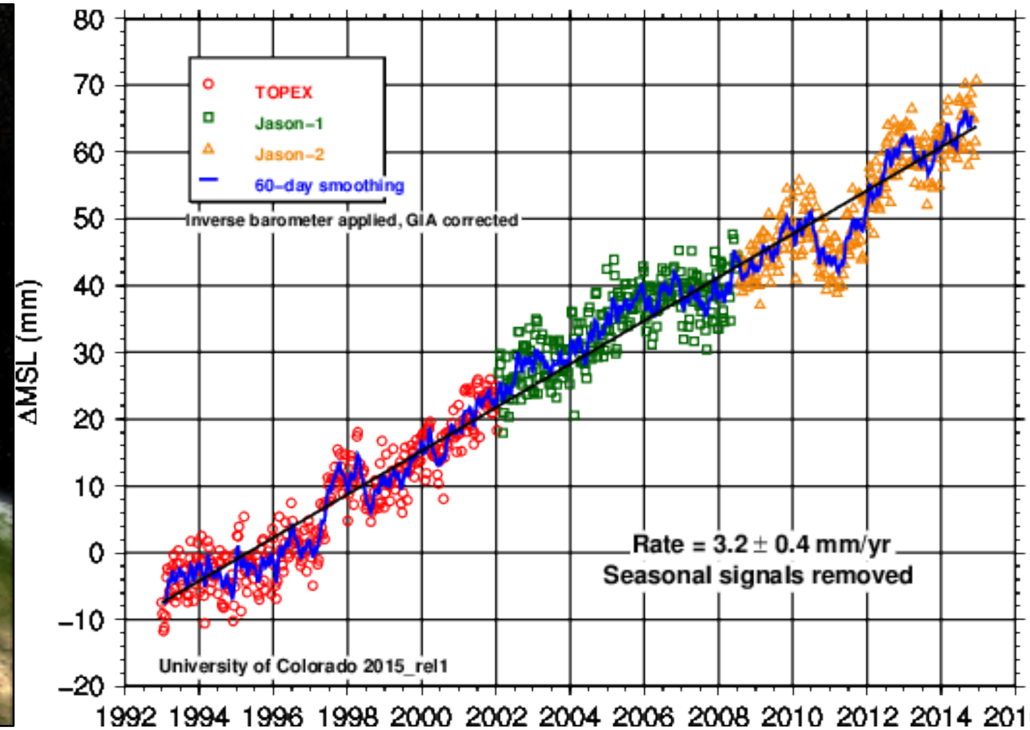
Launch: January 31, 2015



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

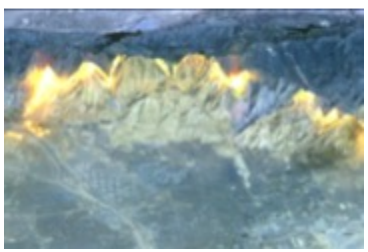
Jason 3: Continuing the Record of Sea Level Rise





Launch Date: July 22, 2015

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
- *Comprehensive* 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

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.

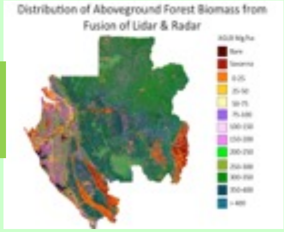
- The NASA NISAR Science Definition Team has developed a set of integrated requirements to respond to the Climate Architecture and other important questions, with ISRO Science participation

- **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

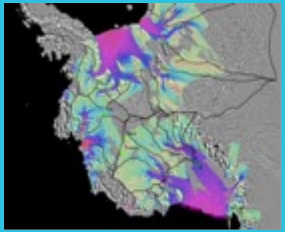
Mission Science

Ecosystem Structure



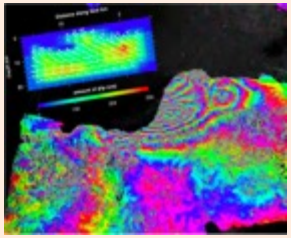
Biomass disturbance; effects of changing climate on habitats and CO_2

Cryosphere



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

Solid Earth

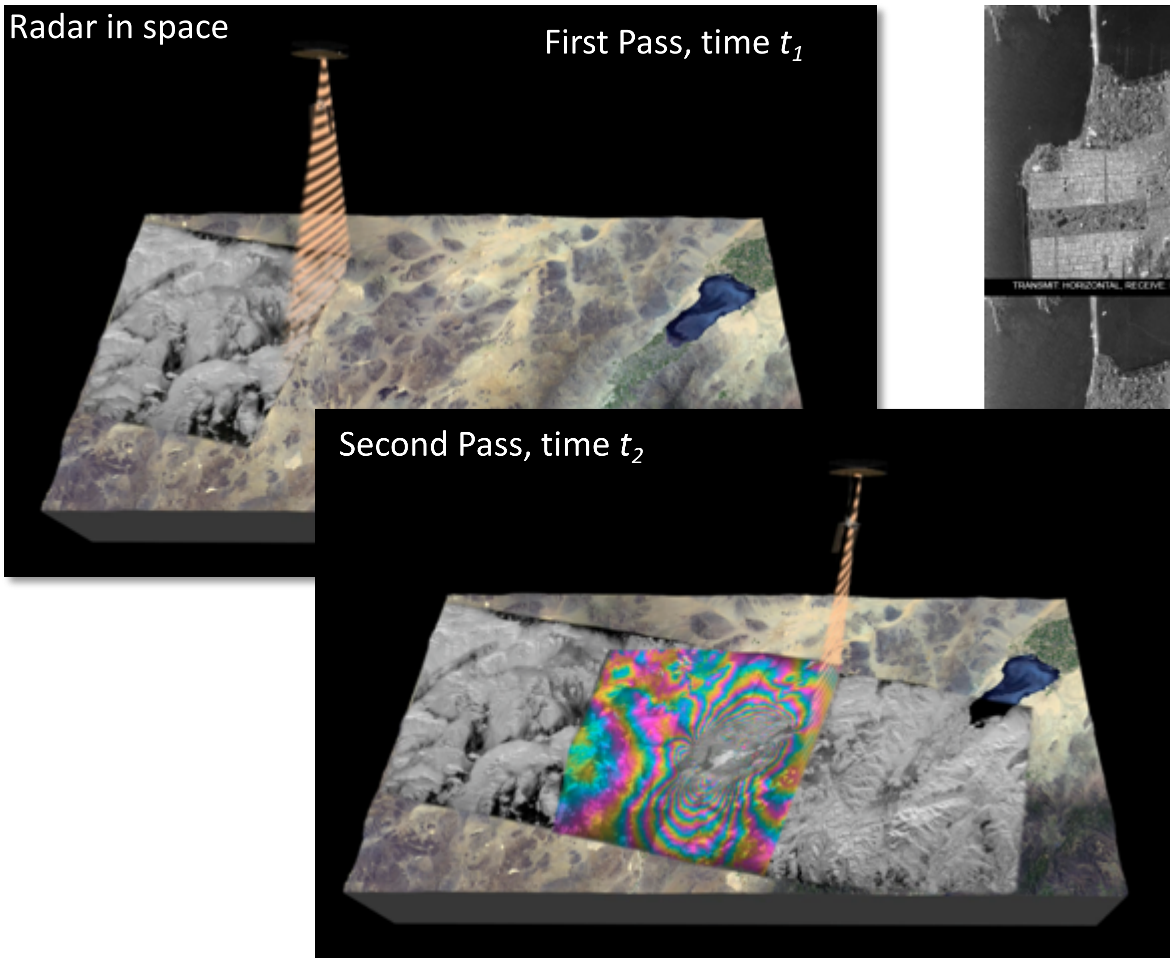


Surface deformation; geo-hazards; water resource management

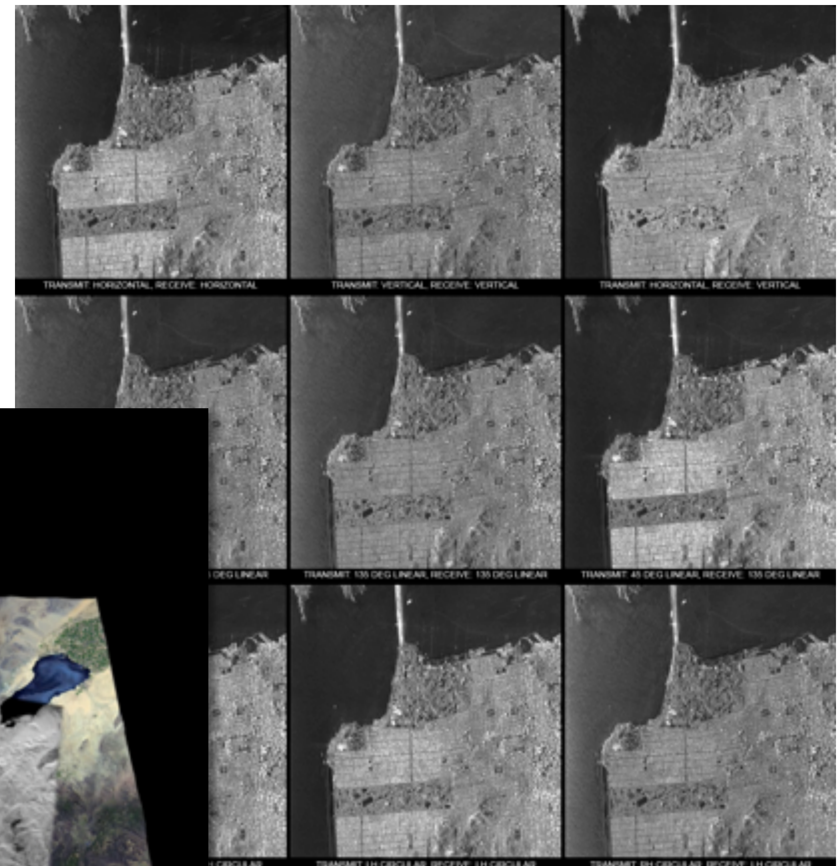
- Directed mission within the Earth Systematic Missions Program under NASA Earth Science Division
- Major international partner: Indian Space Research Organisation (ISRO)
- Baseline launch date: No earlier than December 2020
- Dual frequency L- and S-band Synthetic Aperture Radar (SAR)
  - L-band SAR 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 Measurements to Achieve Science Objectives

Repeat Pass Interferometry

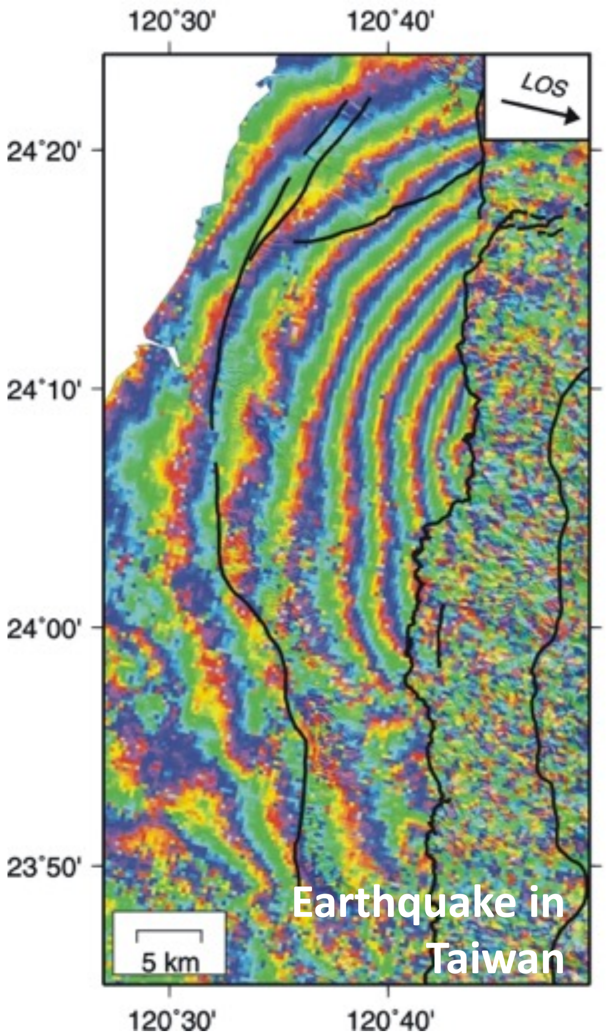


Polarimetric Diversity

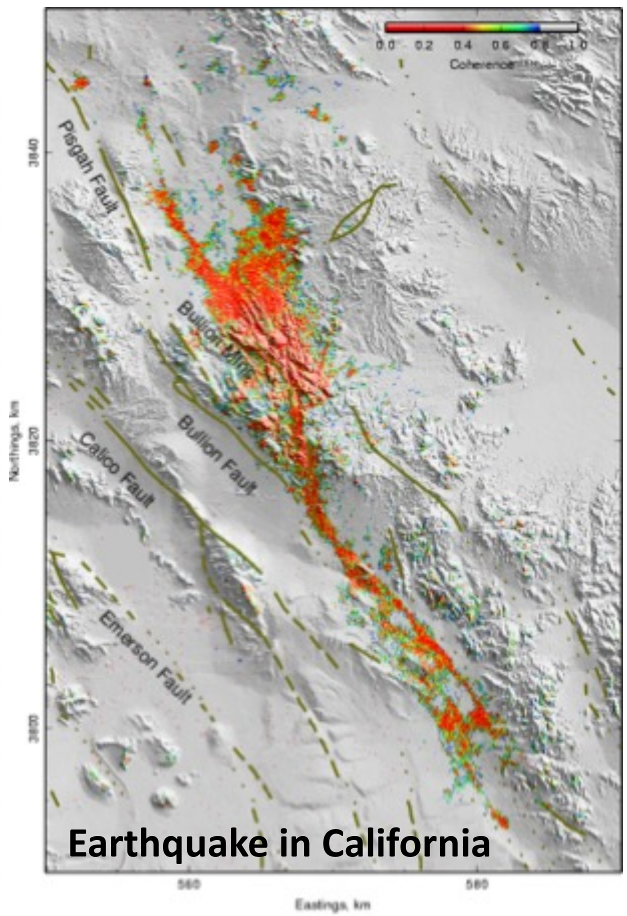


NASA - ISRO SAR Mission

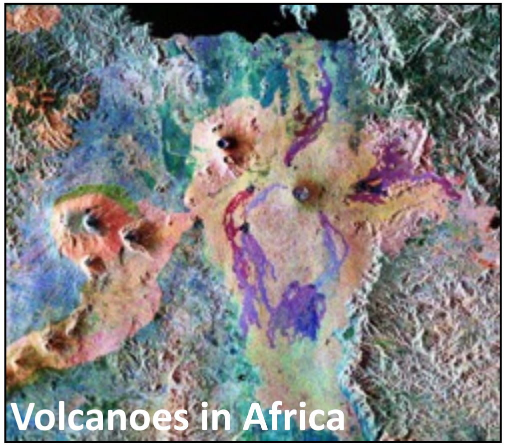
Basic Geodetic & Imaging Measurements



Interferogram – How much motion?



Decorrelation –
How severe the change?

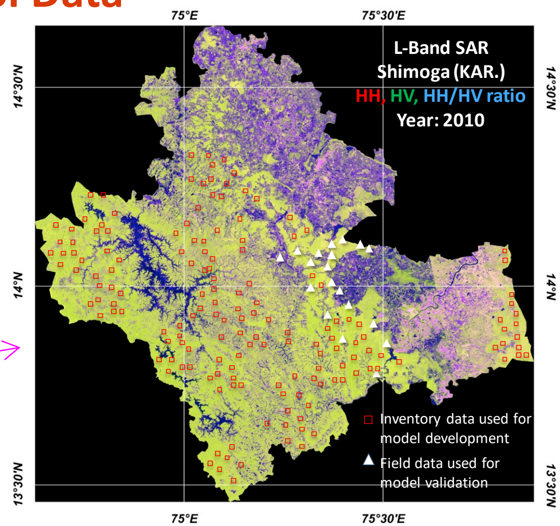


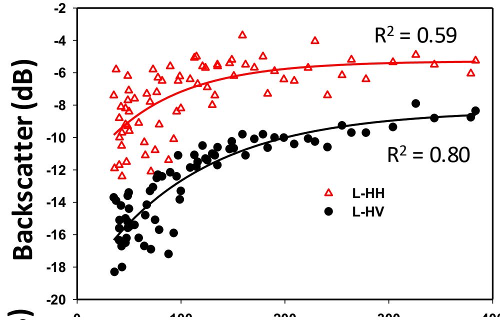
Polarimetry – structure/biomass

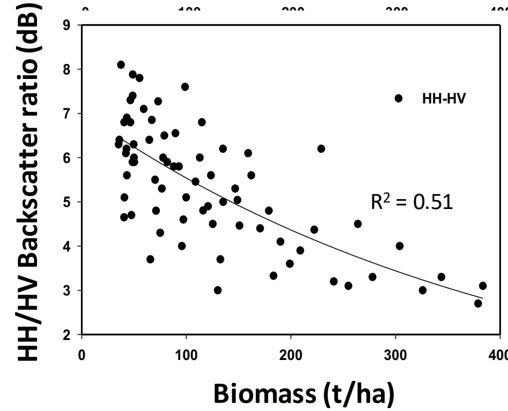
SIR-A over Northwest Sudan Sand Sheet - Funda-mentally not optical

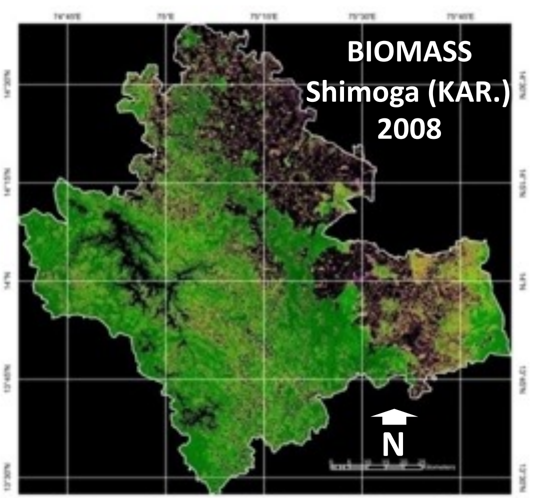
NISAR facilitates above-ground biomass of Indian forests more frequently with better accuracy

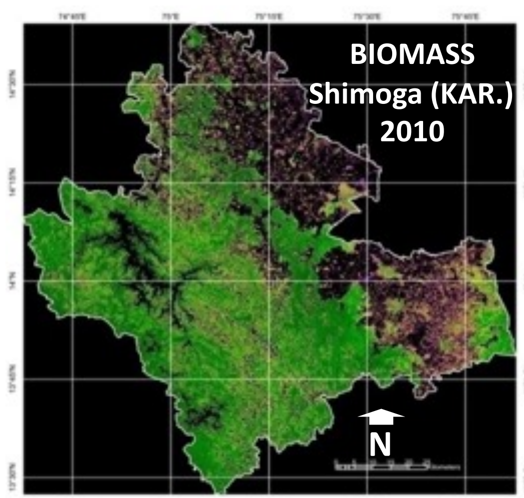
ALOS PALSAR-1 HH+HV pol Data











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

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

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

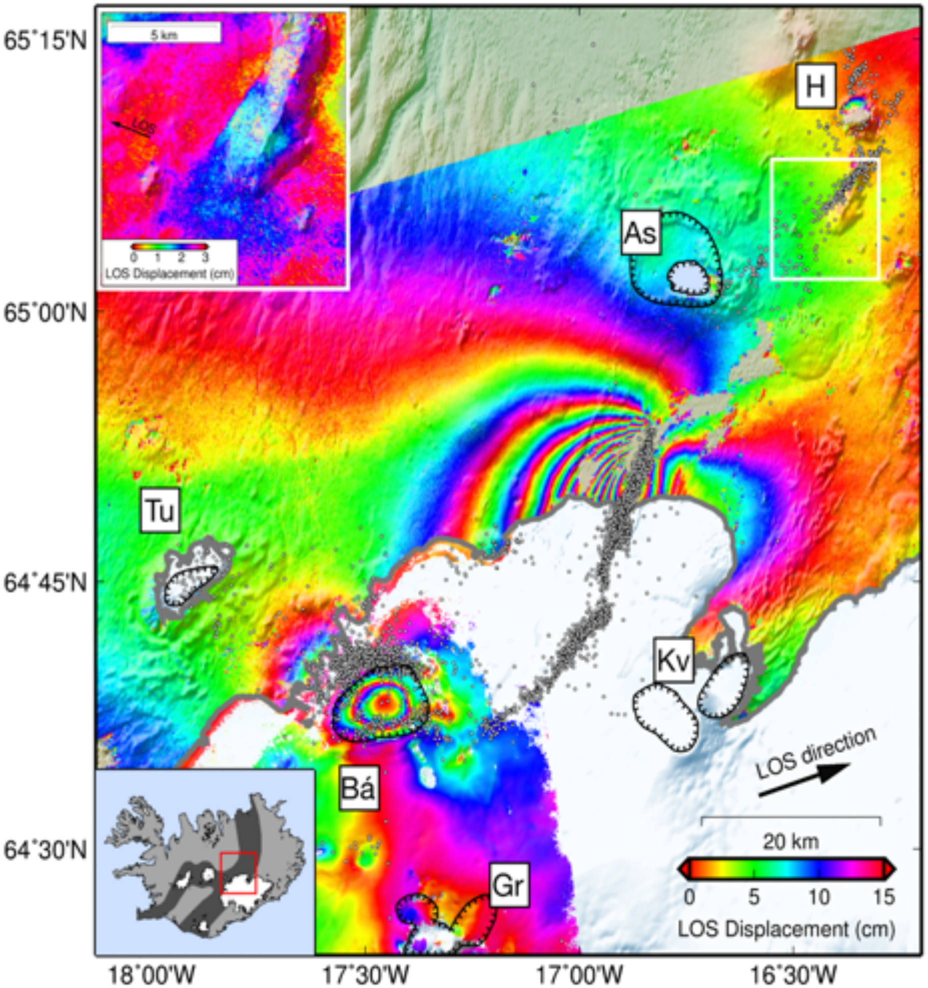
$\sigma\sigma^0$ is backscattering coefficient in dB and A, B and C are the model coefficients

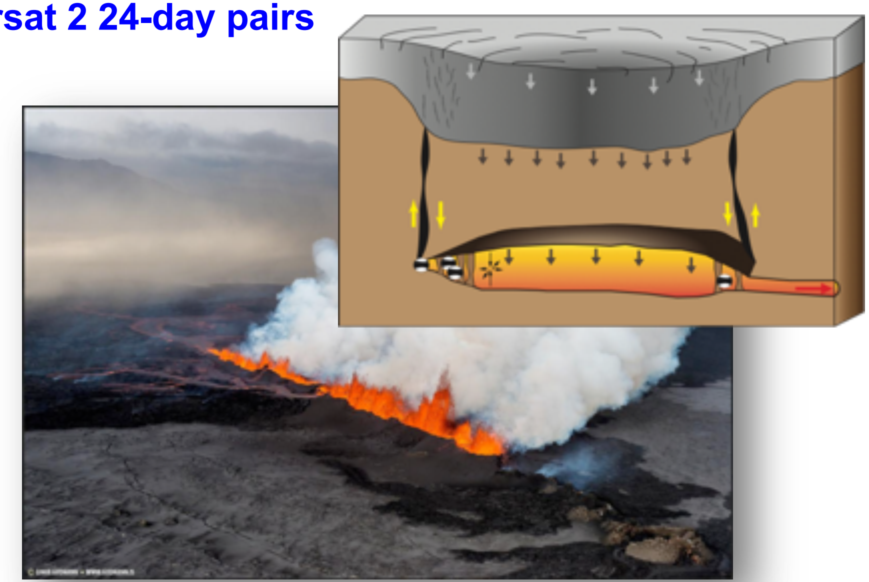
(RMS Error < 25 t/ha for biomass range within 120 t/ha)

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

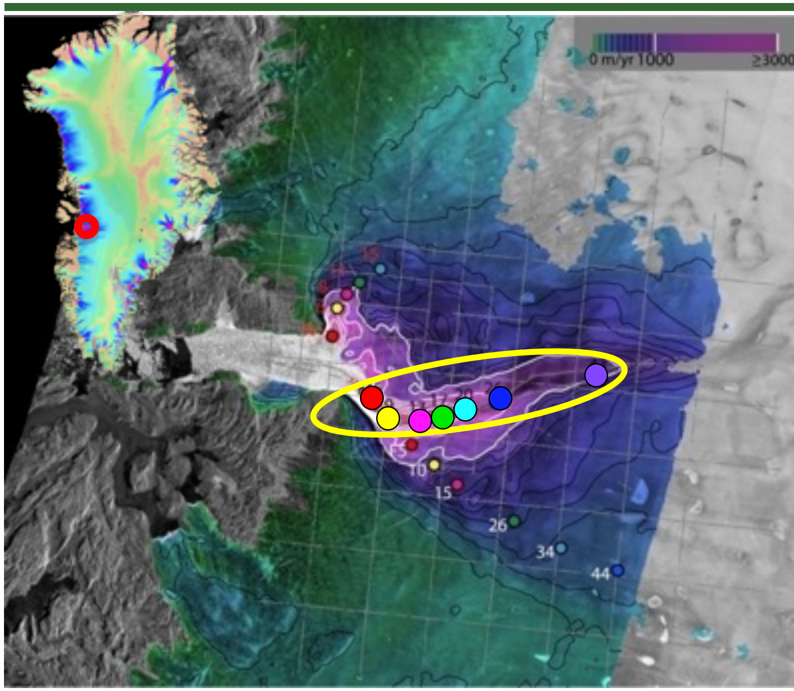


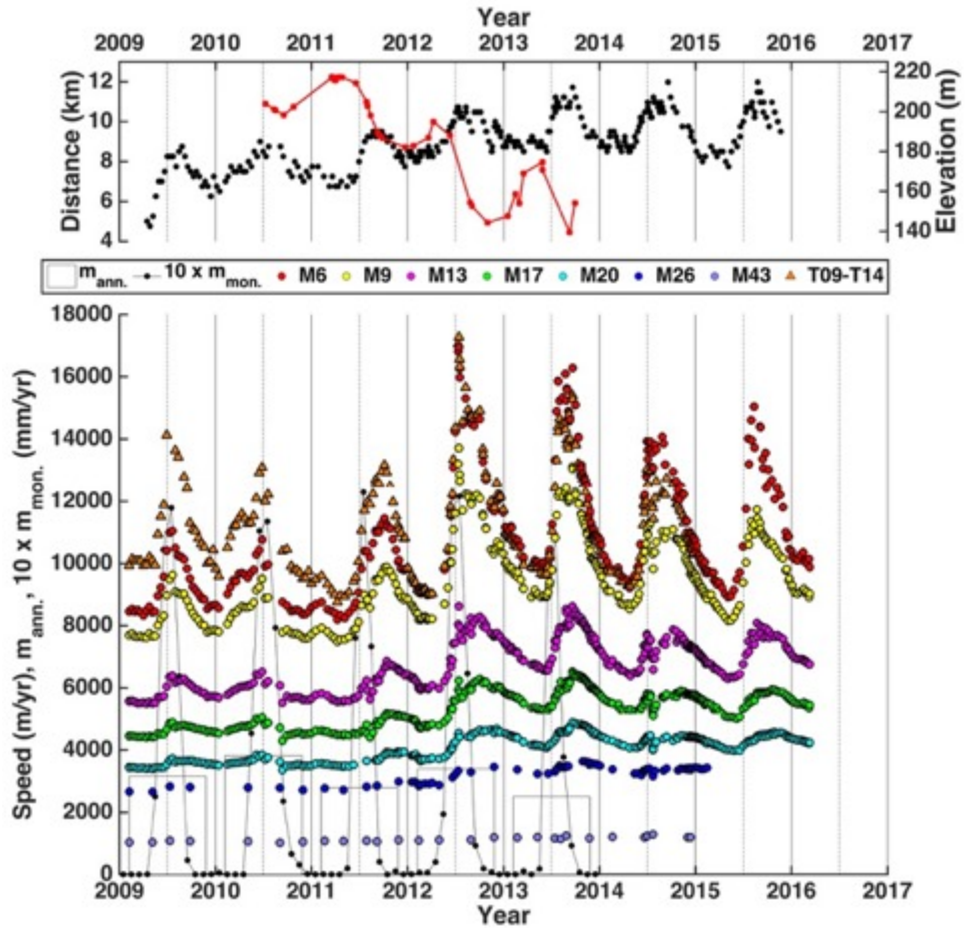


Riel et al., *Geophys. J. Int.*, 2015

Dynamic Ice Sheets

Cryosphere – Dynamic Ice Sheets





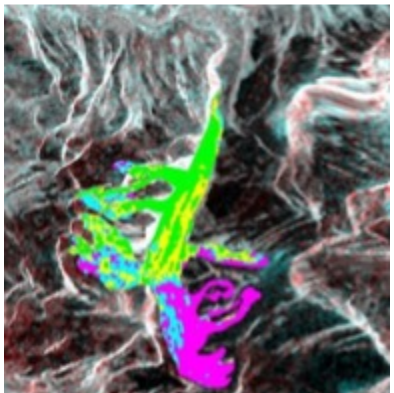
Jakobshavn Isbrae

Update to Joughin et al., 2014

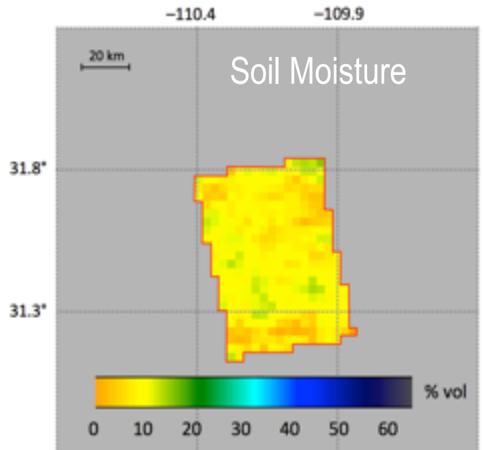
Requires time-varying horizontal velocities at near-weekly sampling intervals in areas of potential rapid or seasonal change to an accuracy better than 3% plus 10 m/yr (1-sigma) at 500-m resolution (> 80% coverage)

Some NISAR Applications Products

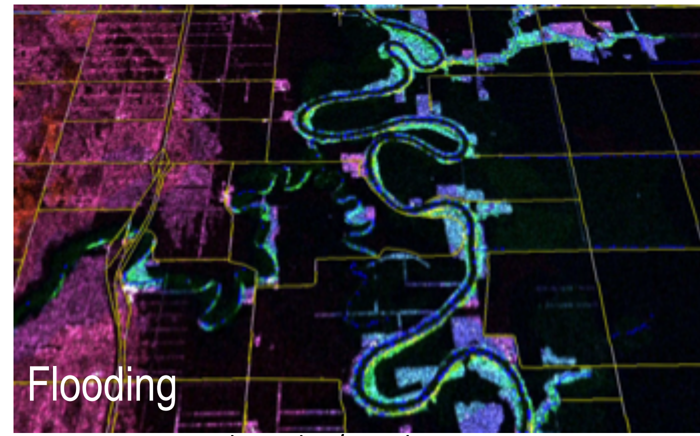
Himalayan Snow Wetness



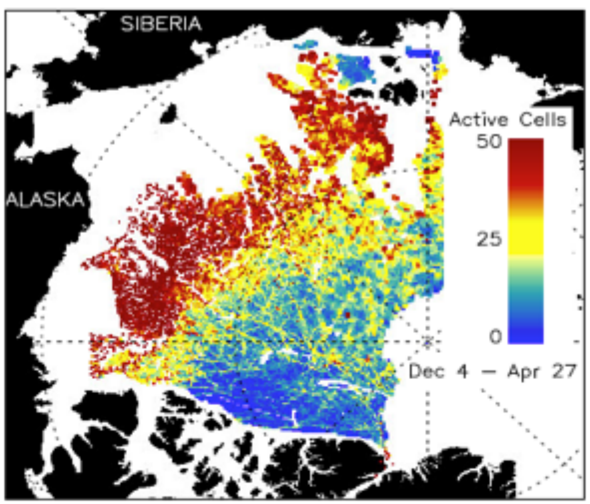
Courtesy: A. Das



Courtesy: M. Lavalle

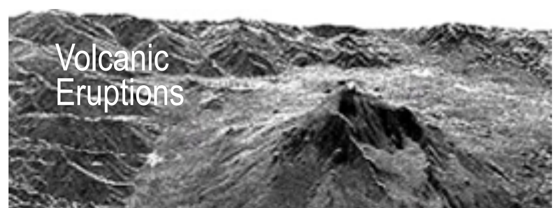


Courtesy: G. Breckenridge/S. Nghiem



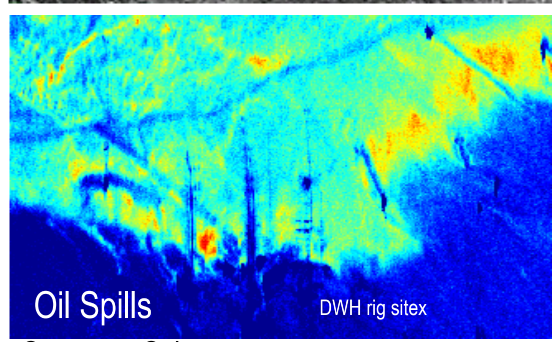
Courtesy: R. Kwok

Sea Ice Extent/ Ice and Ship Tracking

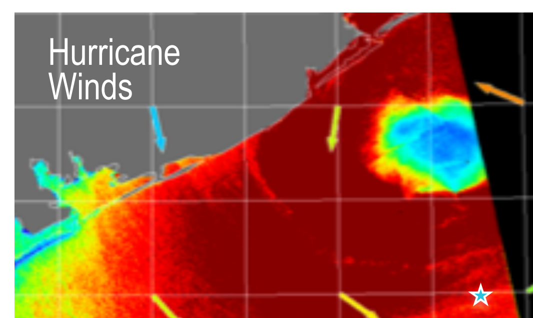


Courtesy: G. Bawden

Courtesy: S.-H. Yun



Courtesy: C. Jones



Courtesy: G. Bawden

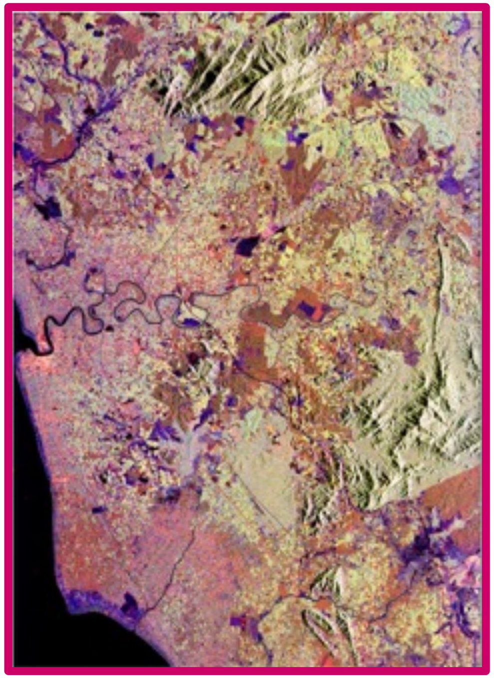
Benefits of both US-contributed L-band SAR and India-contributed S-band SAR

- *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

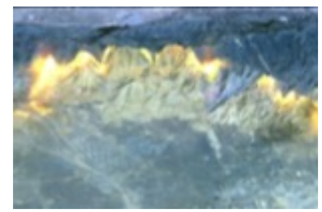
Examples of dual-frequency measurements from SIR-C/X-SAR

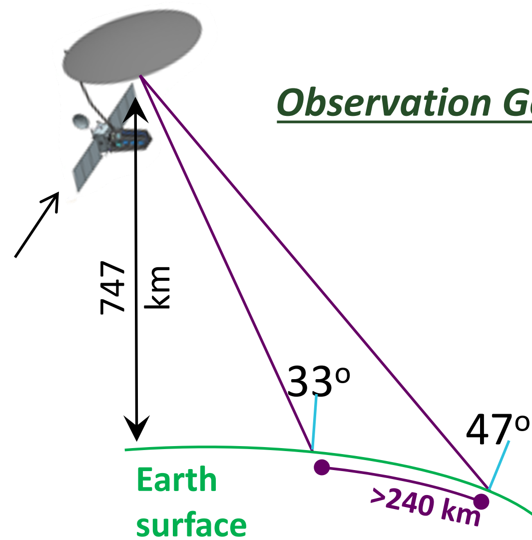
NISAR Concept Science Observation Overview

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

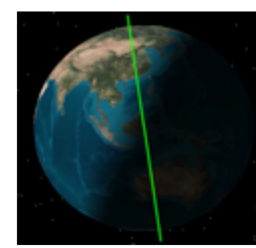
NISAR Will Uniquely Capture the Earth in Motion





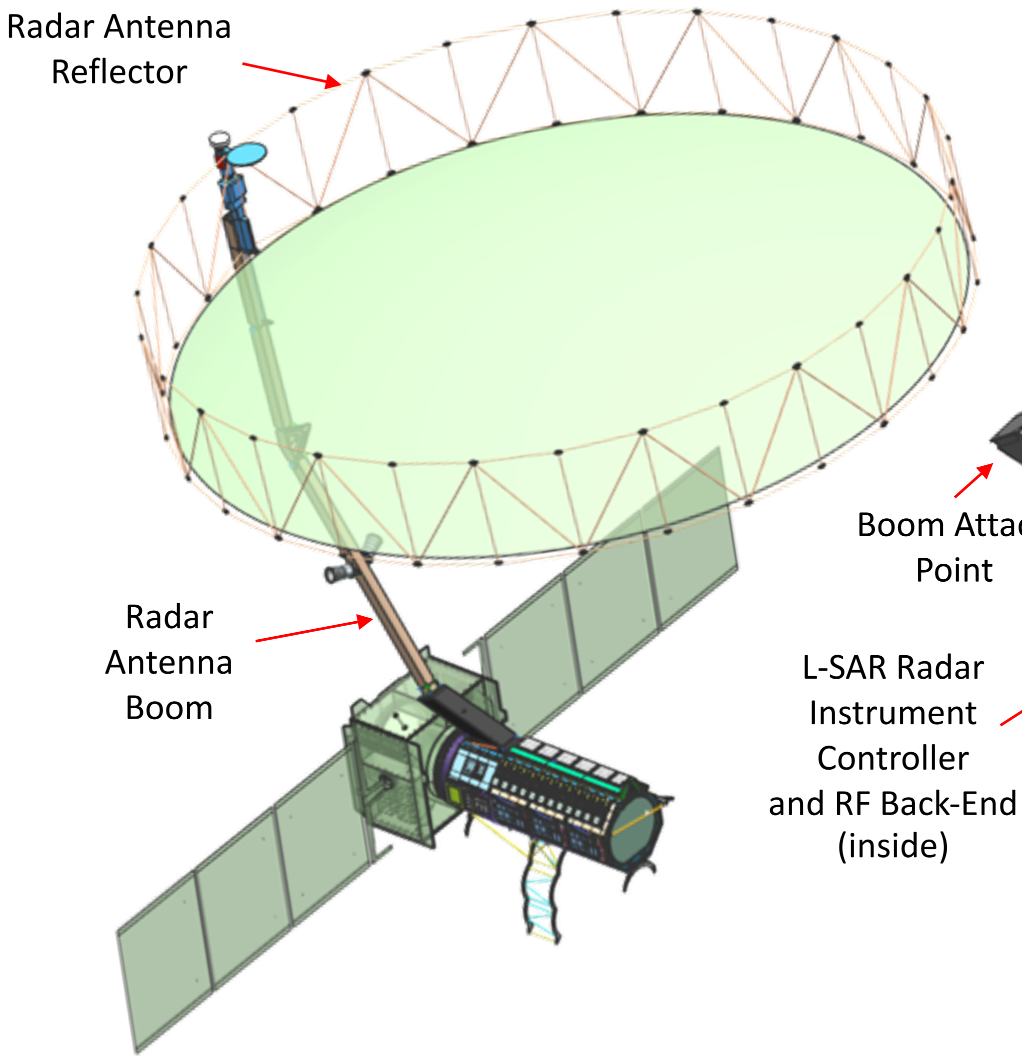



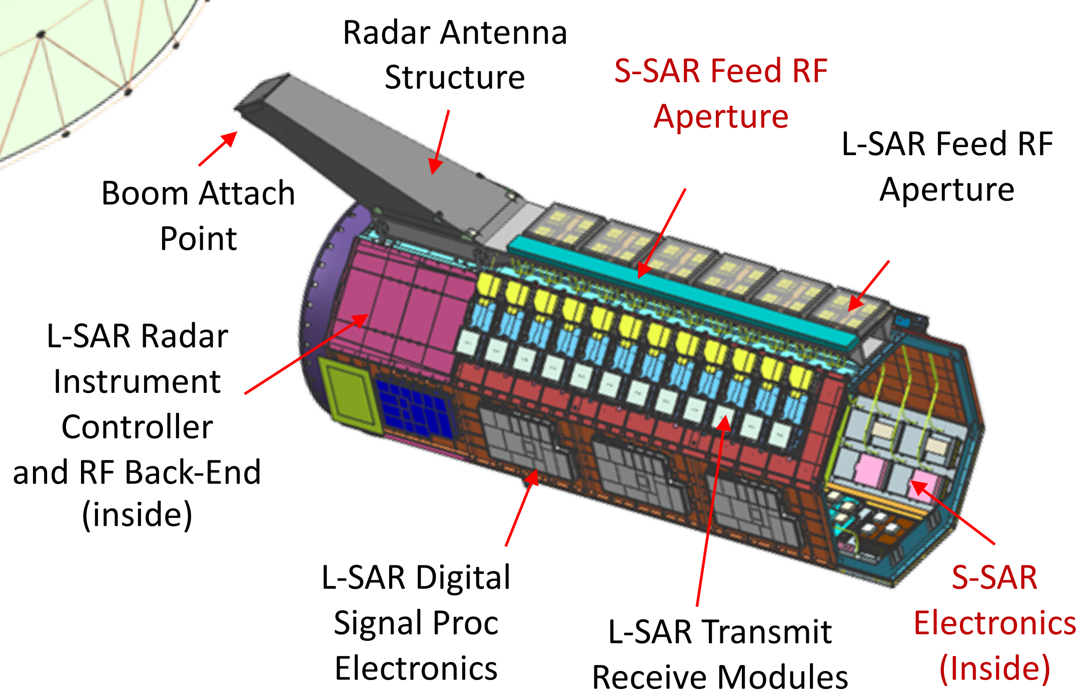
Observation Geometry



NISAR Instrument Overview

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

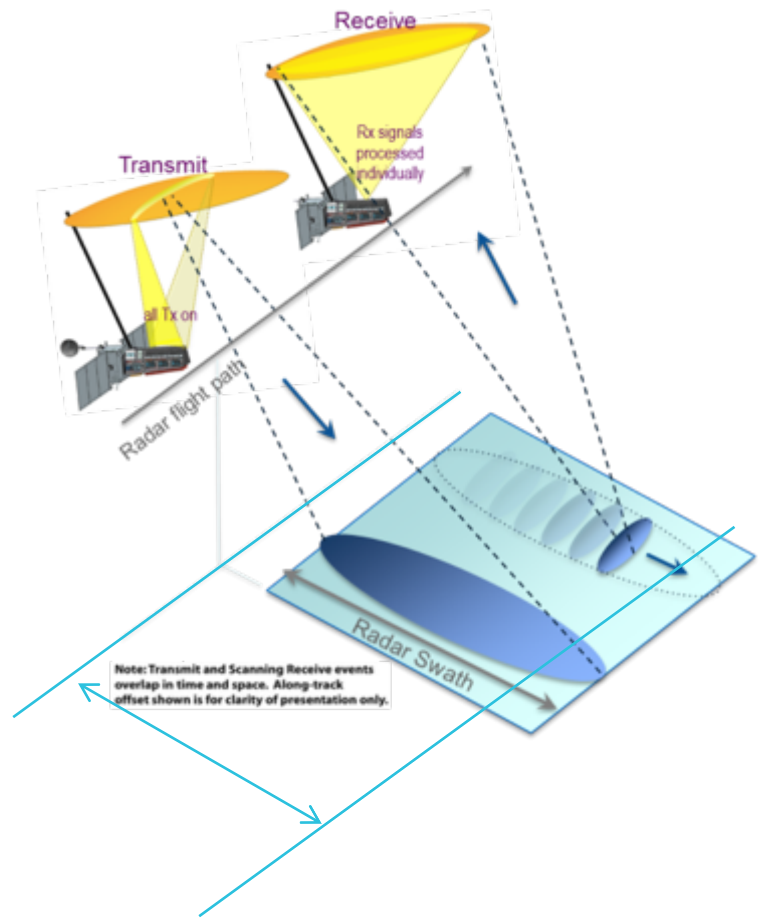




Instrument Structure also houses GPS unit and Solid State Recorder

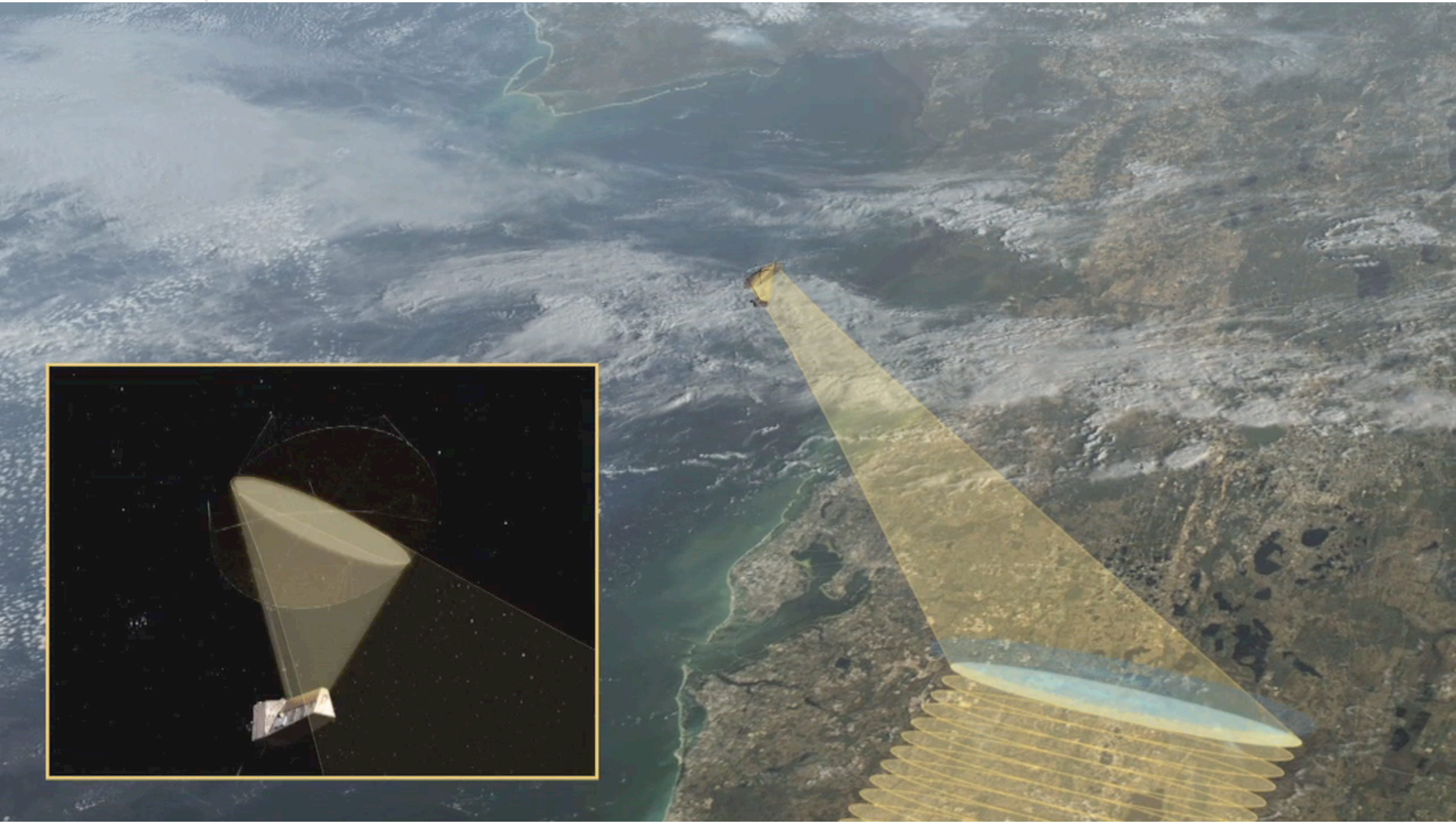
NISAR Swath Coverage

- 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

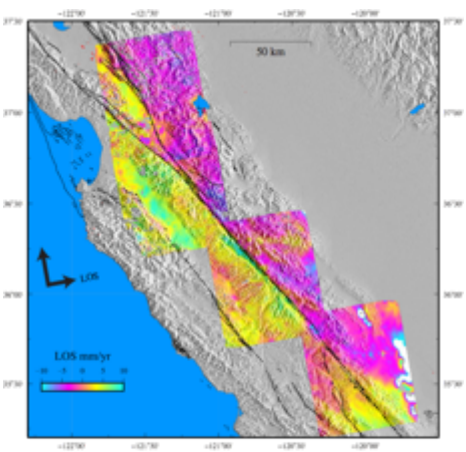


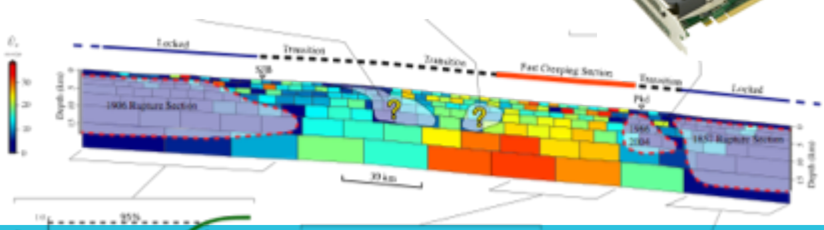
~236 km Earth-fixed ground track spacing at equator for 12-day repeat orbit

NISAR: Illustrating Advanced SweepSAR Concept



NISAR: Key Technologies





In Space

- First-of-a-kind wide-swath reflector-based radar
- High-power GaN amplifiers in transmitters
- On-board digital beam forming through high-speed computing devices and self-calibrating electronics

In the Cloud

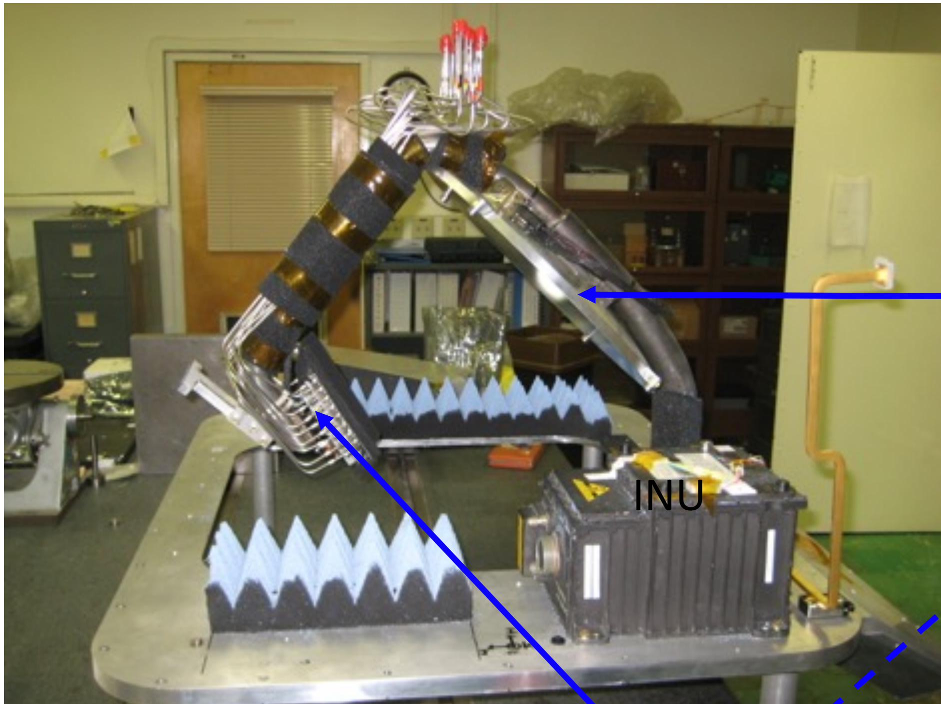
- Petabyte-scale distributed scientific computing of global high-resolution time-series

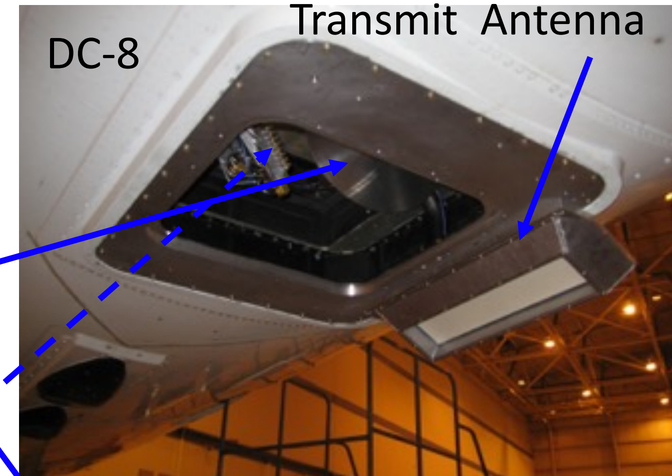
In the Lab

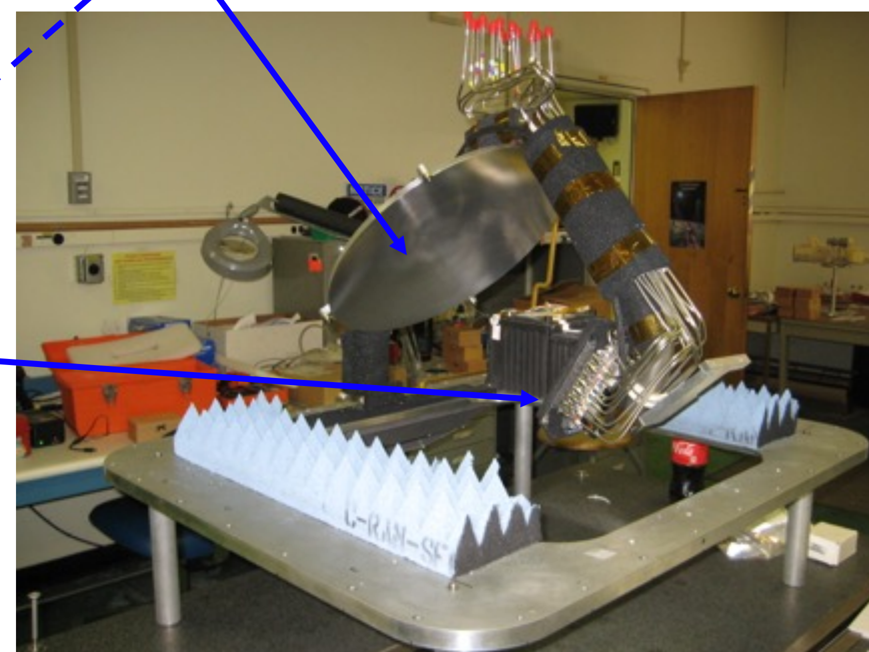
- GPU-based distributed/cluster computing for solving problems of big coupled systems

NISAR NASA - ISRO SAR Mission

Ka-band Scaled SweepSAR Demonstrator



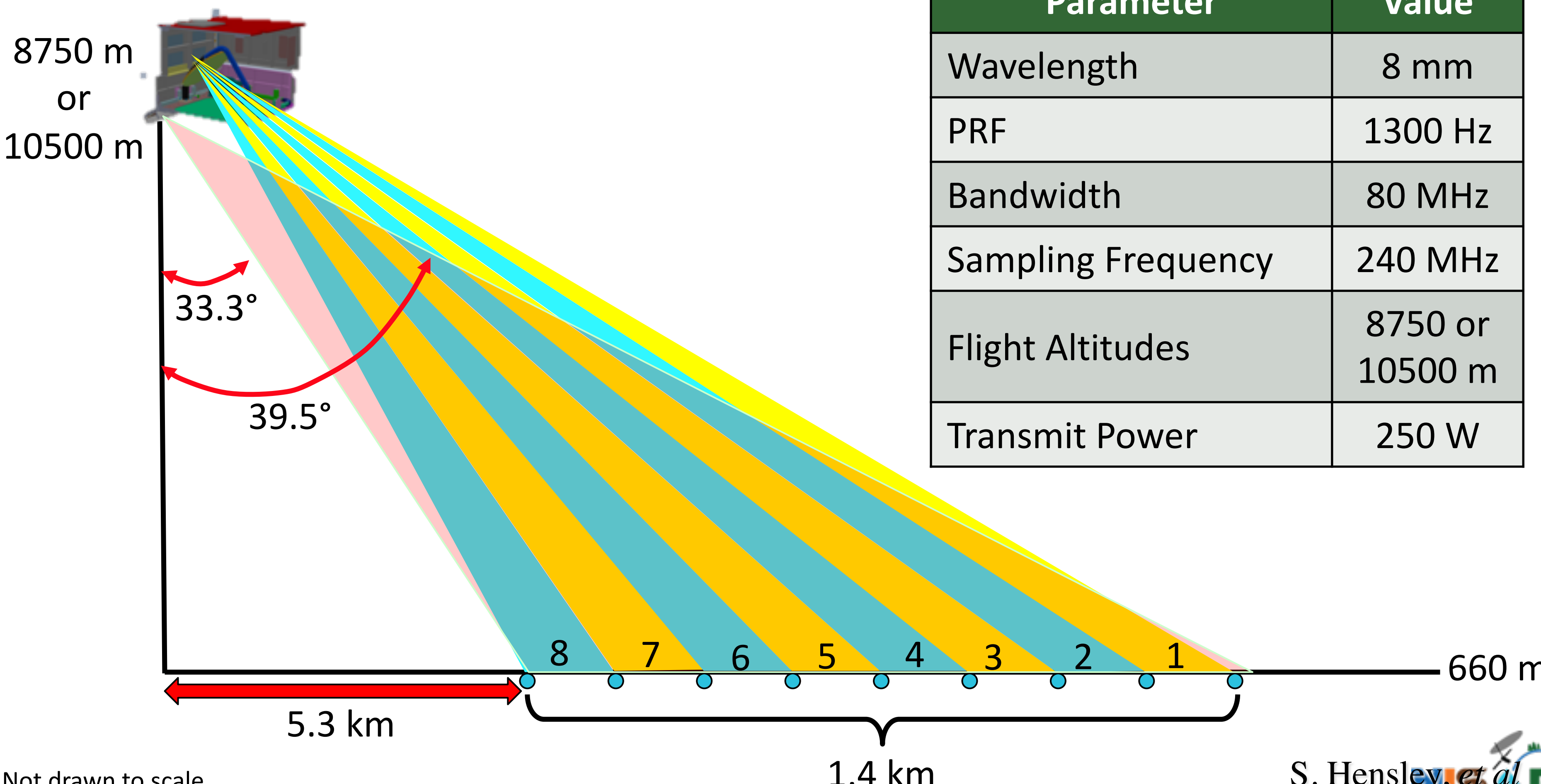




From: S. Hensley, *et al*, “First Results from an Airborne SweepSAR Demonstration at Ka-band” IGARSS 2011

Ka-band Demonstrator Radar Parameters and Mapping Geometry

- The eight beams map a swath extending from 33.3°-39.5° that gives a swath width of 1.4 km



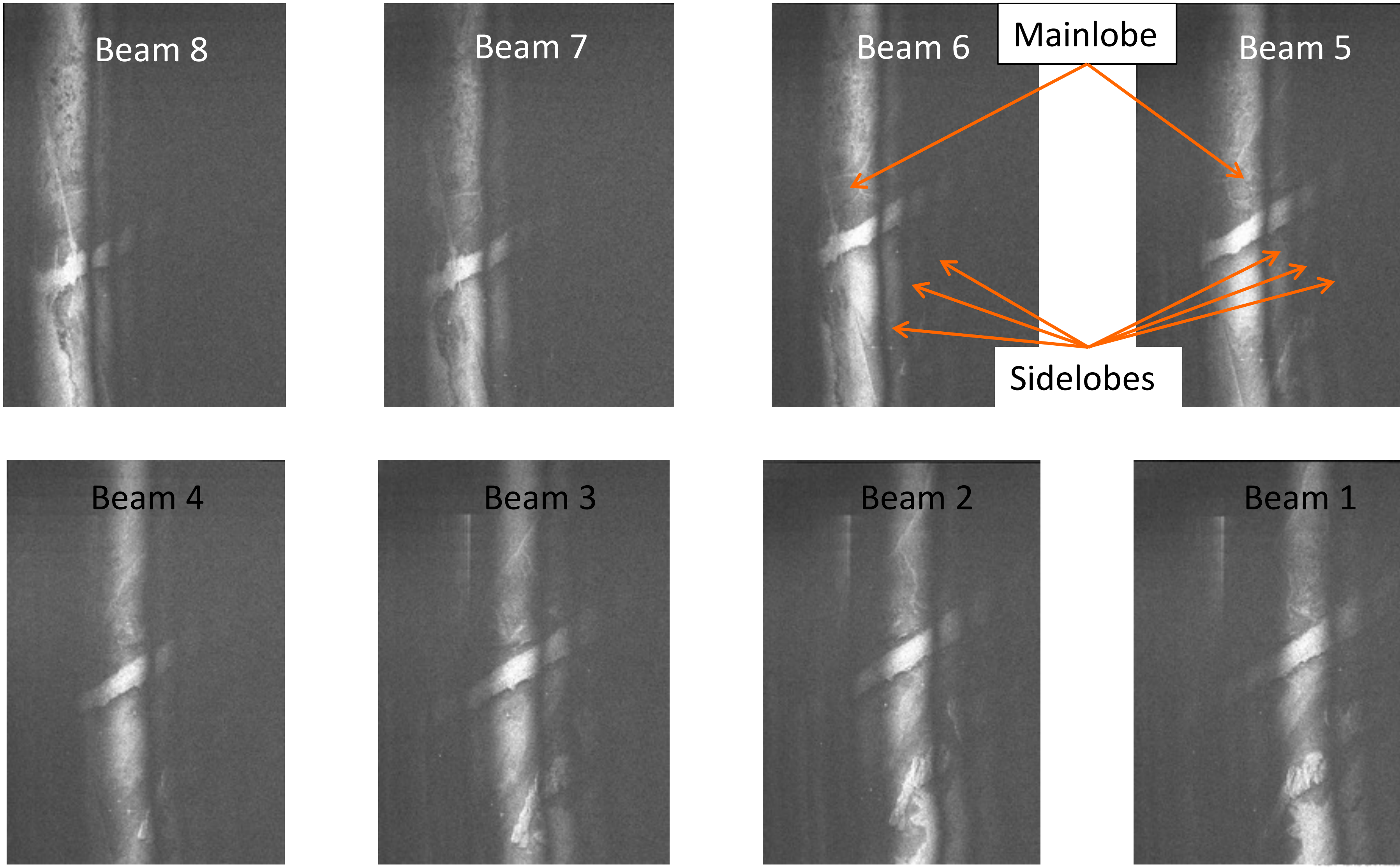
Not drawn to scale

Radar Parameters

Parameter	Value
Wavelength	8 mm
PRF	1300 Hz
Bandwidth	80 MHz
Sampling Frequency	240 MHz
Flight Altitudes	8750 or 10500 m
Transmit Power	250 W

S. Hensley, *et al*

Ka-band Individual Beam Imagery



S. Hensley, *et al*

SweepSAR Airborne Demo Data Processing

- Processed data from 6 flight lines to show results are consistent and repeatable from pass to pass
- Analyzing impulse response from corner reflector data to quantify beam combining effects on image performance
- Now running airborne data through prototype flight hardware to combine beams in real time

Image from Flight Line 3

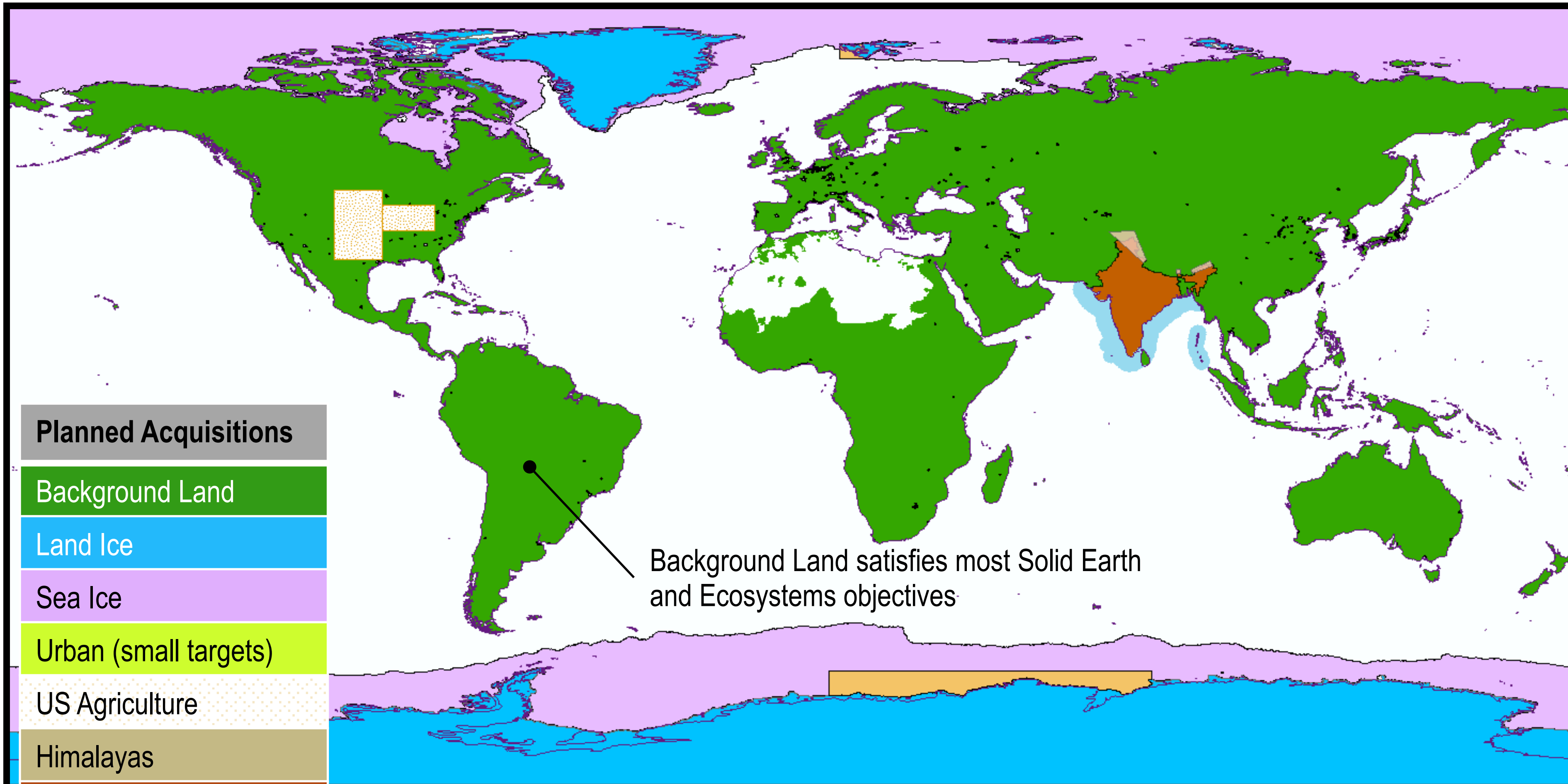
Image from Flight Line 7

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	↙

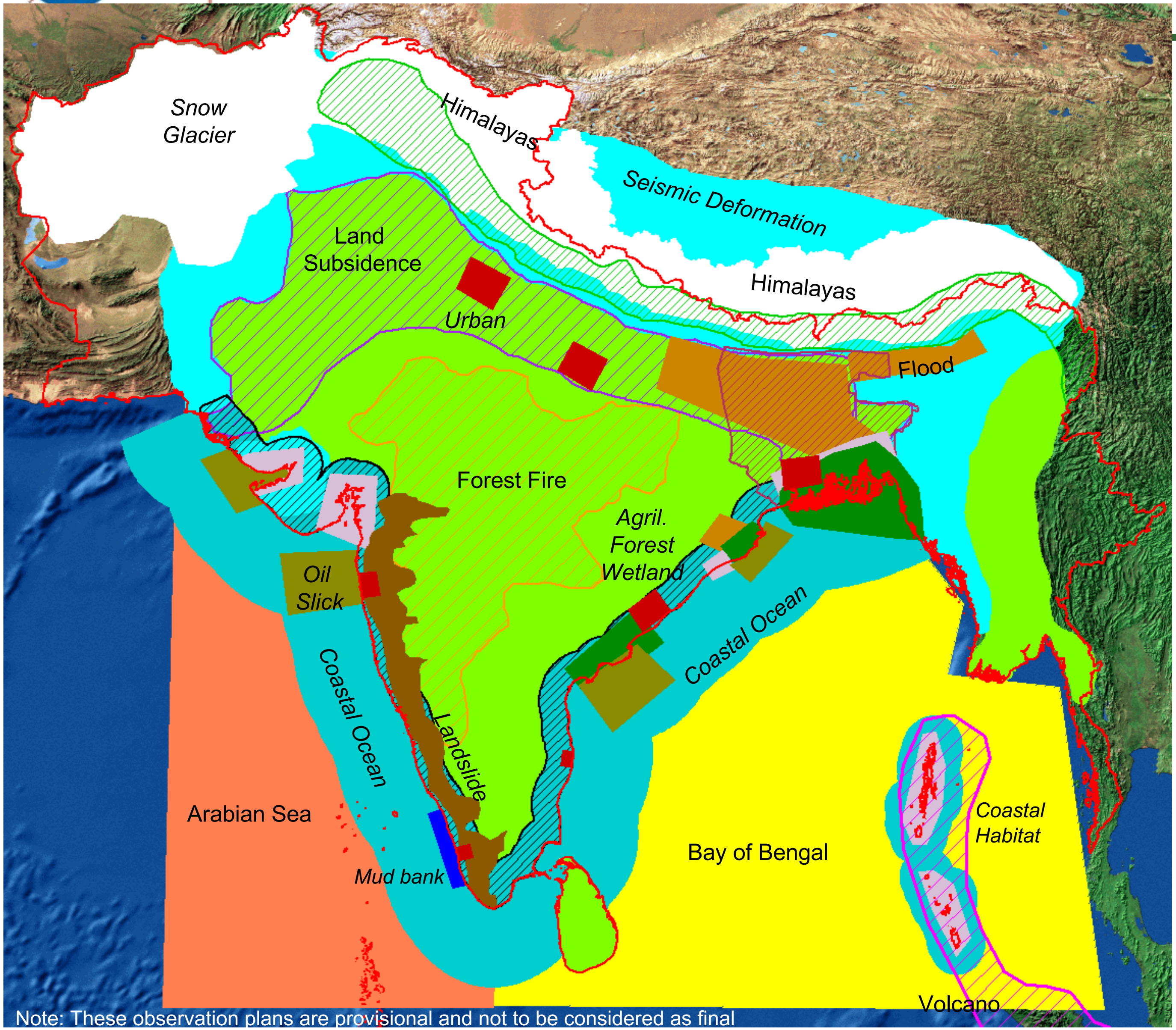
Mode-Specific Science Targets in Observation Plan



- 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

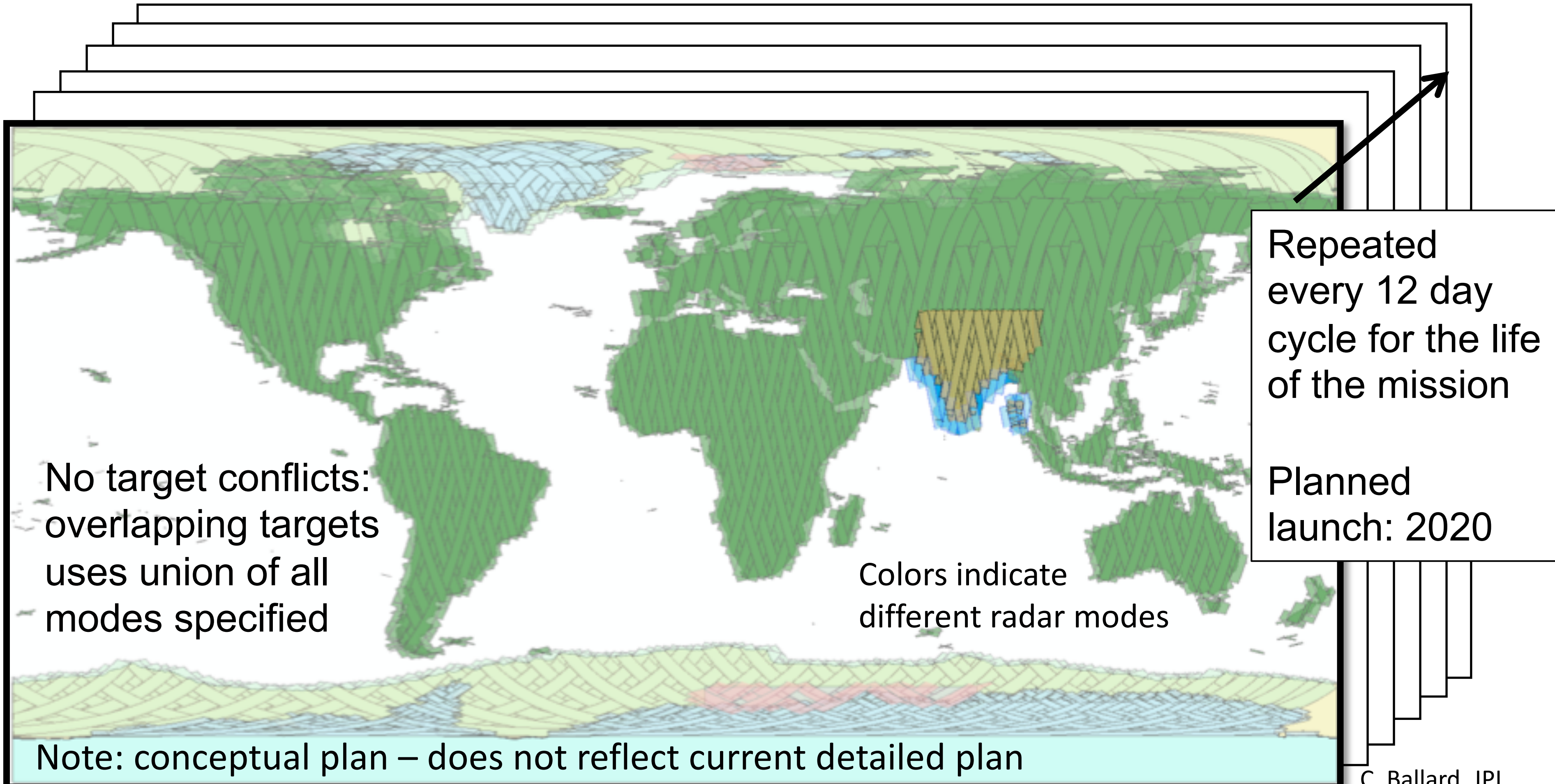
Additional polar targets augment NASA coverage



- 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

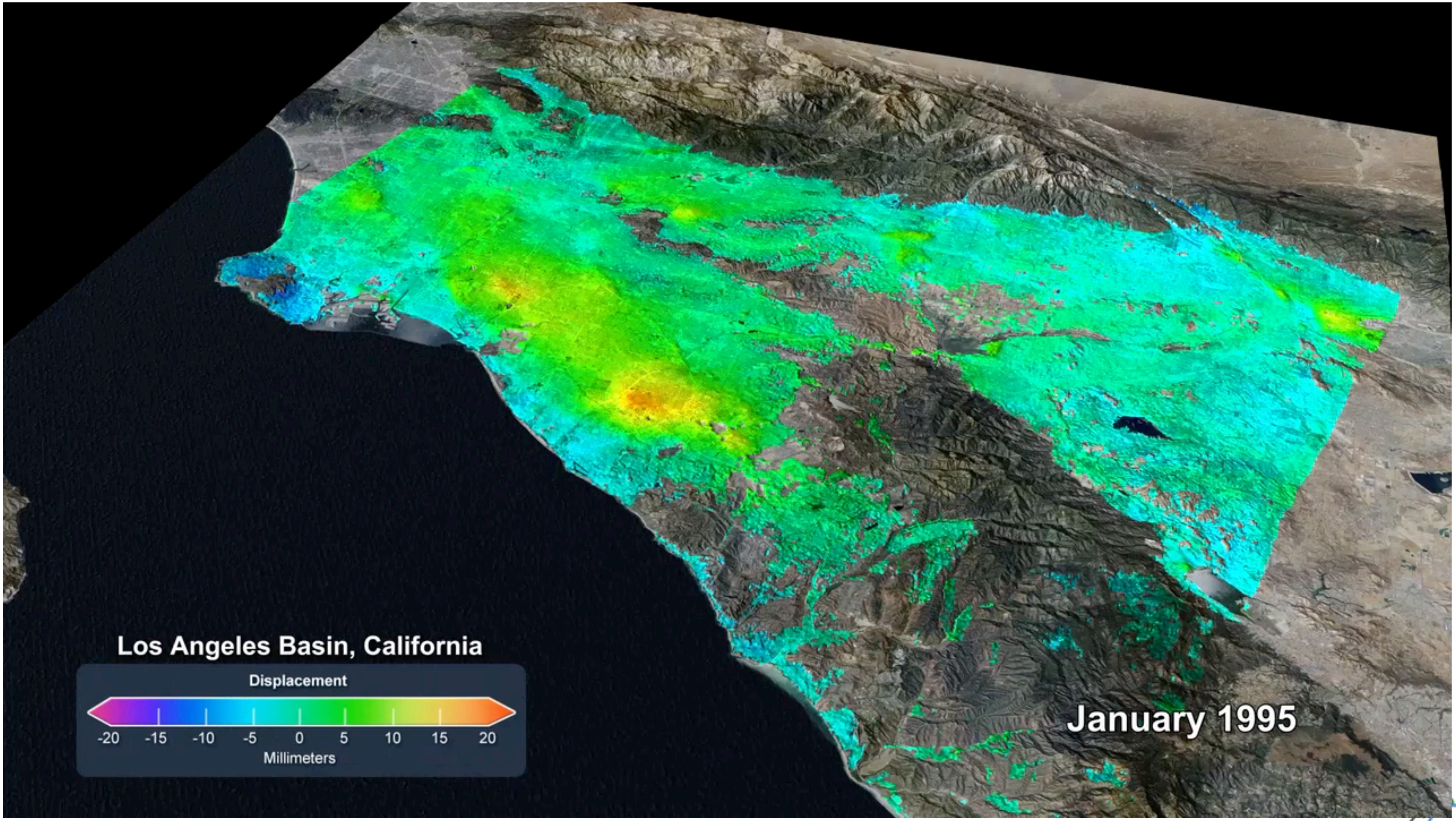


Persistent updated measurements of Earth

Societal Challenges and What SAR Can Contribute

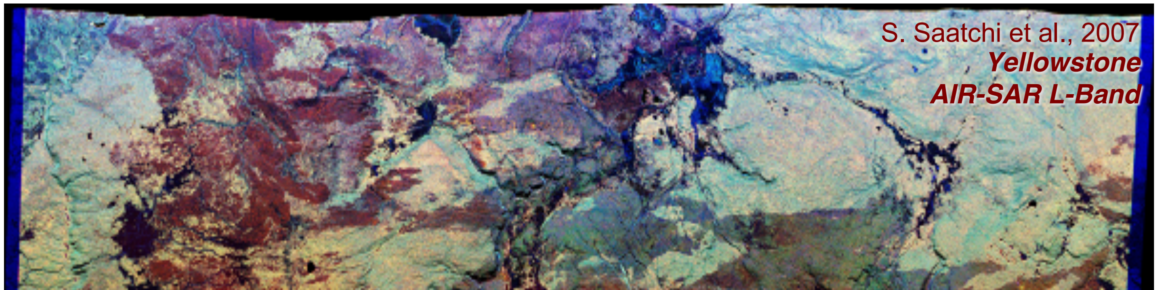
Challenge	Benefit Through Regular SAR Monitoring of:
Global Food Security	- Soil moisture and crop growth at agricultural scale - Desertification at regional scales
Freshwater Availability	- Aquifer use/extent regionally - Water-body extent changes - Glaciers serving as water sources
Human Health	- Moisture 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

LA Aquifer Utilization - Seasonal Component



Global Monitoring of Vegetation Disturbance and Recovery

NISAR will provide annual vegetation disturbance and deforestation maps globally at spatial scale of ~1 ha



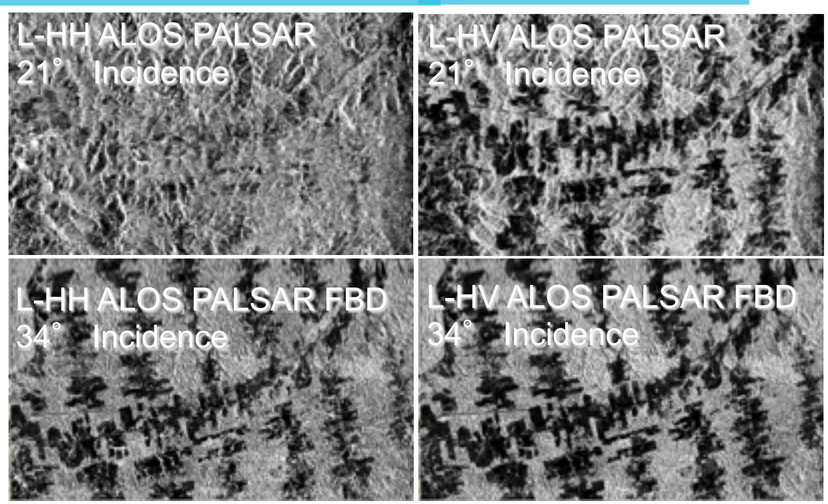
Cross-pol measurement is key to detecting structural differences in vegetation, driving requirement for multi-pol baseline and cross-pol threshold radar capability.

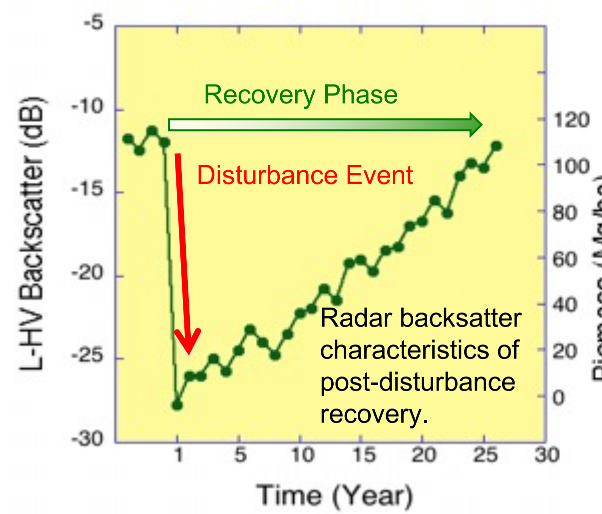
2003 Burn

Recovery after 1988 Burn

Pine Beetle Disease

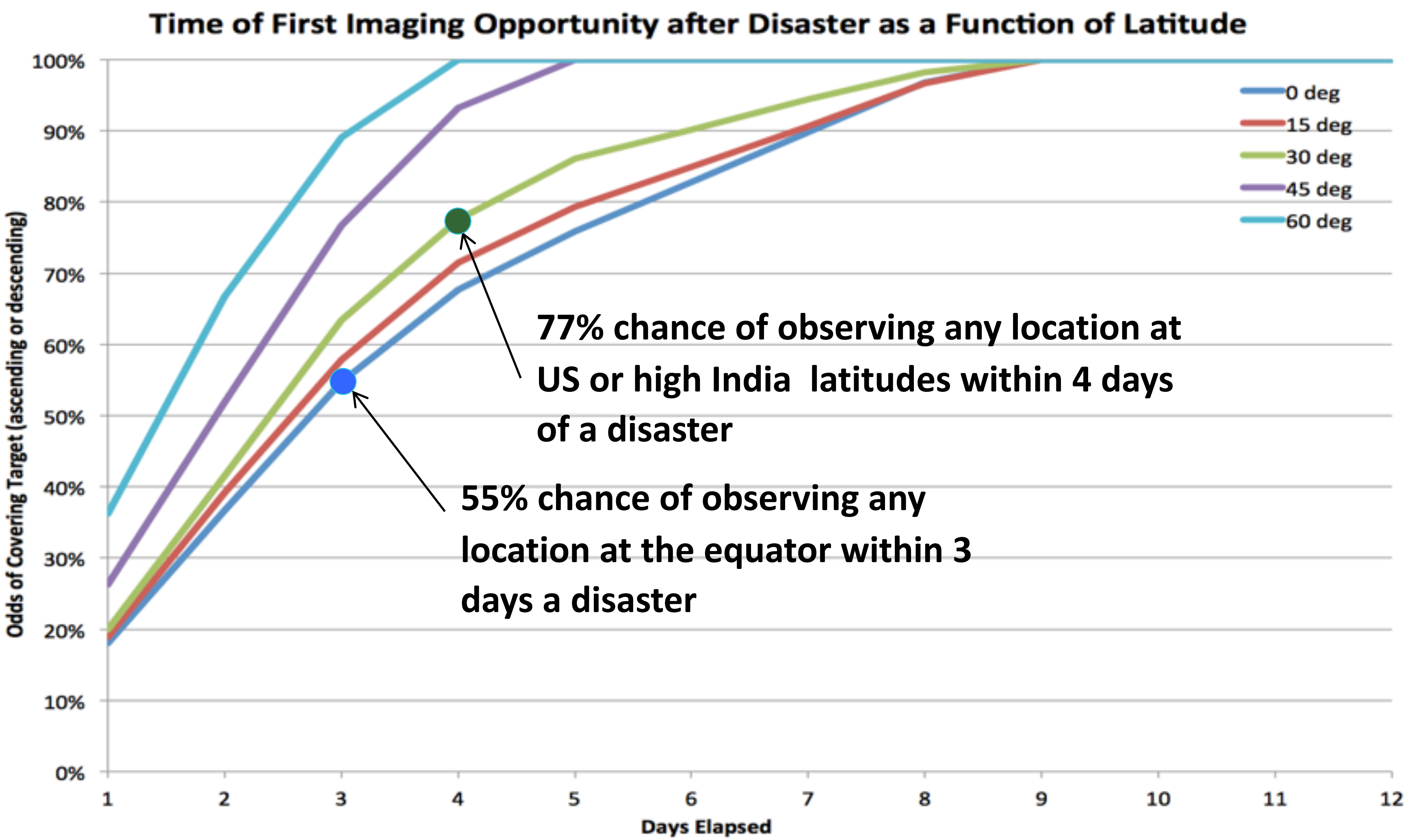
NISAR will provide acquisitions with both polarization and incident angle variations; both critical for effective disturbance monitoring.



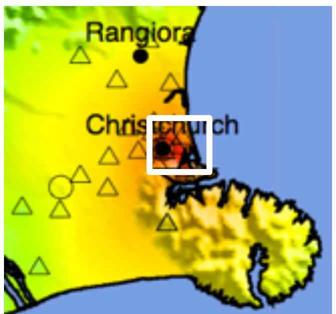


NISAR will quantify fluxes in terrestrial sources and sinks of carbon resulting from disturbance

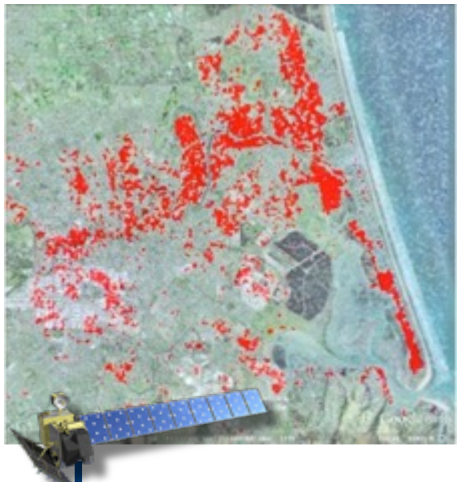
NISAR Mission Concept
Rapid Response Time-to-Image



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

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

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, with launch planned in 2021