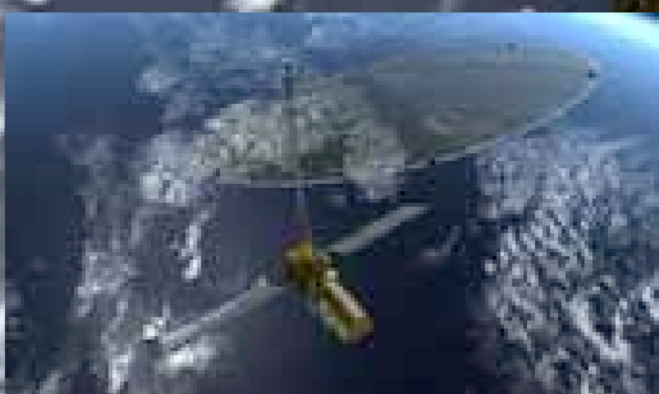
NASA-ISRO SAR Collaboration

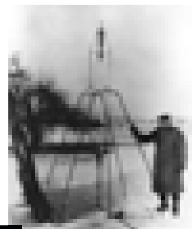
Monitoring the dynamic Earth from Space - a NASA-ISRO Radar Mission

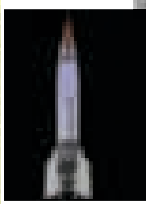
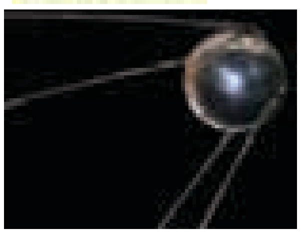


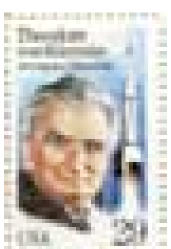
Mr Alok Chatterjee, Mission Interface Manager
Dr Paul Rosen, Project Scientist

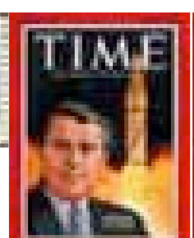
Dynamic Earth

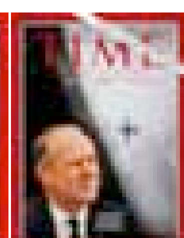
The Births

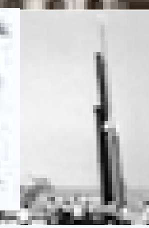
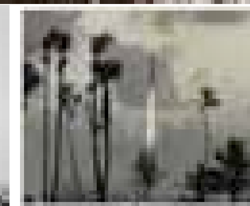








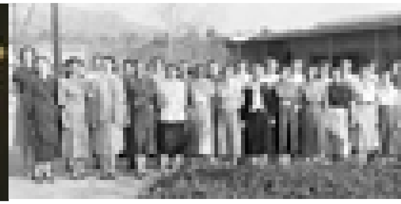


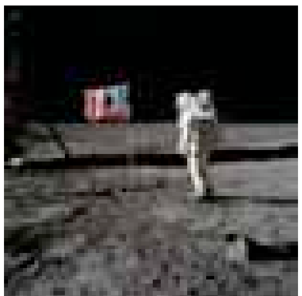




NASA Growth

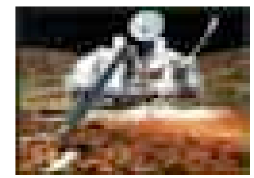
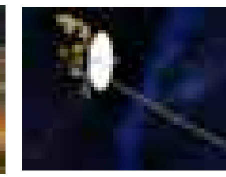



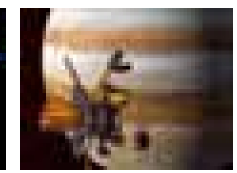
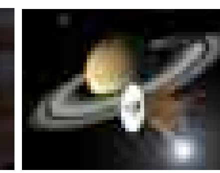








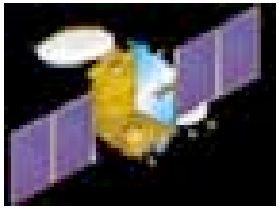




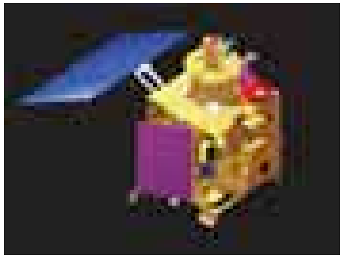
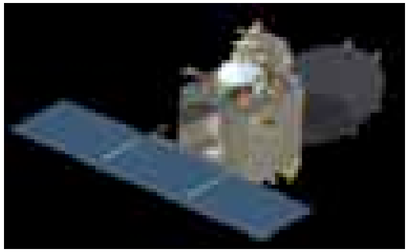
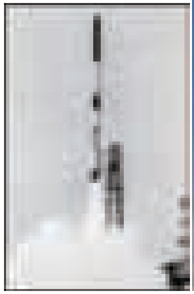



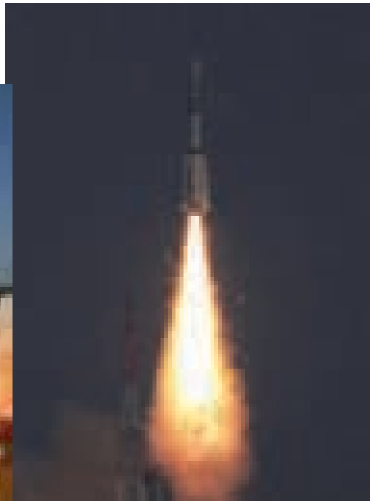

ISRO GROWTH



Chandigarh
Dehradun
New Delhi
Lucknow
Jodhpur
Shillong
Ahmedabad
Bhopal
Kharagpur
Mumbai
Nagpur
Hyderabad
Tirupati
Sriharikota
Hassan
Bangalore
Thiruvananthapuram
Mahendragiri

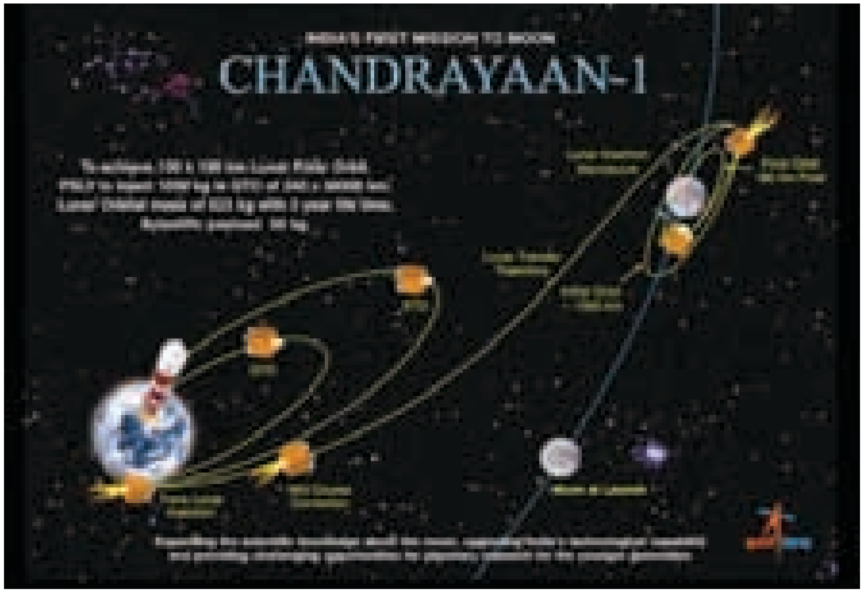



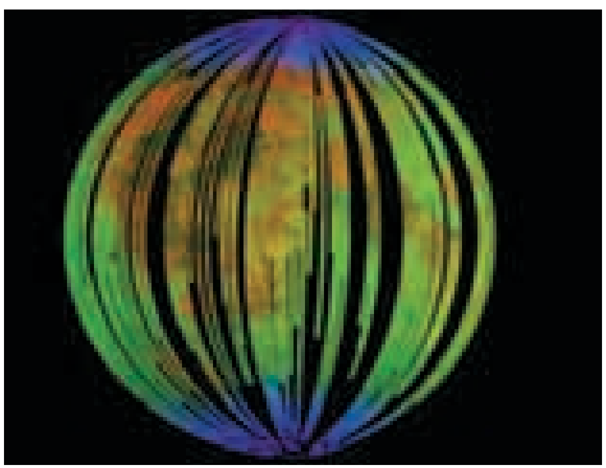




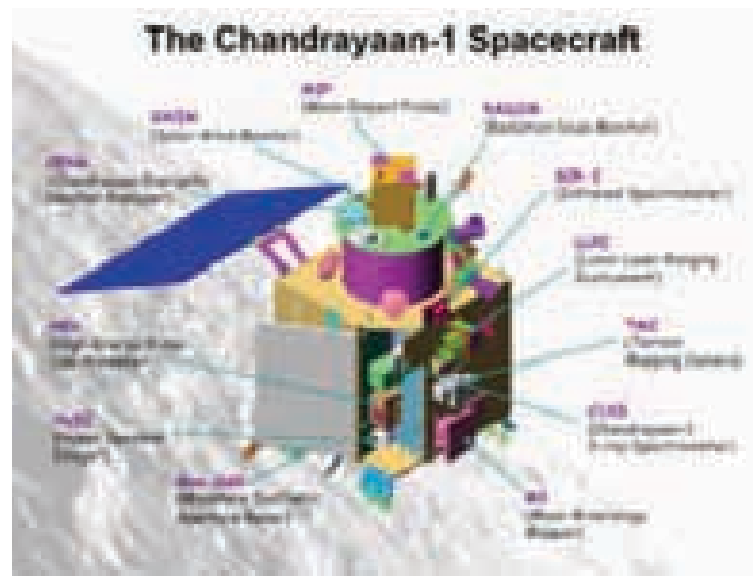



Pioneers & Builders

Chandrayyan-1 NASA-ISRO Collaboration







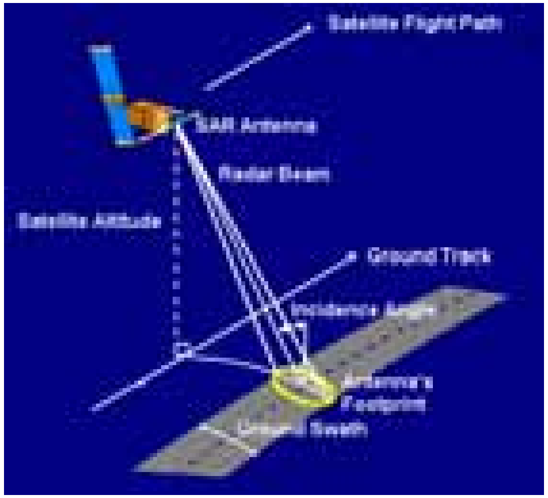
JPL Teams at ISRO to Support Chandrayaan-1 Mission

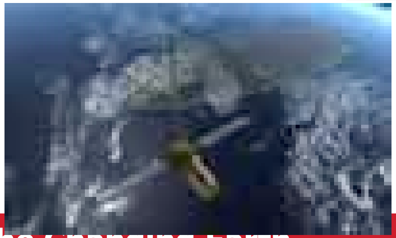
NASA/ JPL Navigation Support for ISRO Mangalyaan mission

- **JPL Navigation Support:**
  - First time ISRO mission going beyond Earth-Moon system into deep space
  - JPL navigation expertise in deep space trajectory and maneuver design provides validation and critical backup to the ISRO Flight Dynamics Team
- **JPL Tracking Support:**
  - Provides continous coverage to track and control the spacecraft's safe journey to Mars
  - DSN's global coverage (Goldstone, Madrid, Canberra) will provide backup tracking support when the spacecraft is not visible to the ISRO Deep Space Network (IDSN) at Bangalore (32m)
  - DSN's very large 70m stations will provide coverage of the critical activities during the Mars Orbit Insertion (MOI) on Sep 24 2014
  - JPL/DSN Validation of IDSN deep space tracking capabilities
- **"Good luck" peanuts**

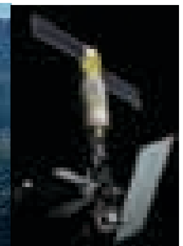
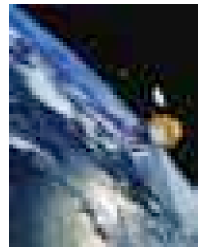
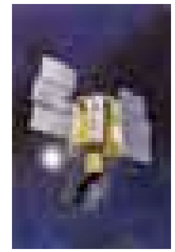
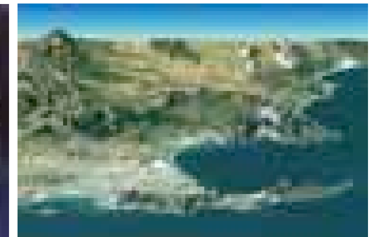
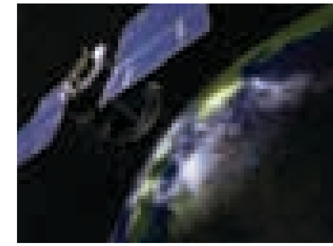
Use of Spaceborne Radar for Earth Observation

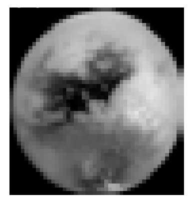
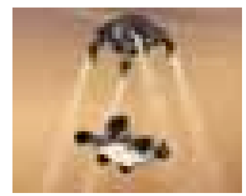
- Use of electo-magnetic microwaves in RAdio Detection And Ranging (RADAR) technology and application (> 1 GHz)
- Synthetic aperture radar (SAR) for high-resolution imaging to observe the dynamics of Earth from space
- Provides a global high resolution measurements of changes in land, water and ice environment
- Radar altimetry to measure the ocean topography
- Scatterometer to measure wind speed and direction
- L (1-2 GHz) and S (2-4 Ghz) have useful space application for monitoring earth changes

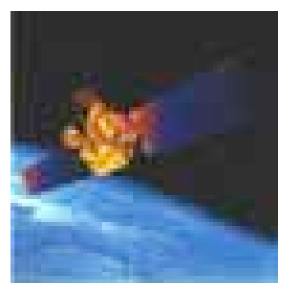


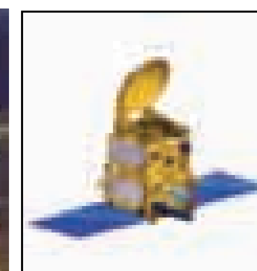


Space Radar Development

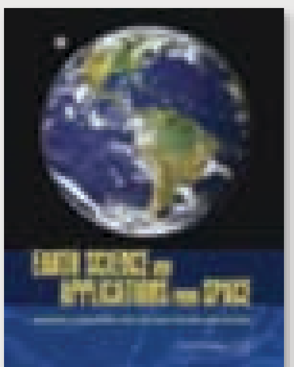





2008 2009 2012 2013

NASA-ISRO SAR SCIENCE INSPIRED BY THE 2007 NRC DECADAL SURVEY AND NASA CLIMATE ARCHITECTURE

- 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.



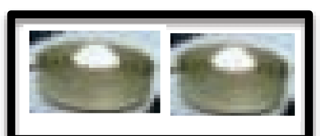
- The NASA/ISRO SDT has developed a set of integrated requirements to respond to the Climate Architecture and other important questions

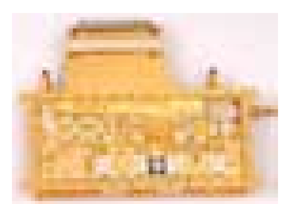
- **Dynamics of Ice: Ice sheets, Glaciers, and Sea Level**
  - *Will there be catastrophic collapse of the major ice sheets, including Greenland and West Antarctic and, if so, how rapidly will this occur?*
  - *What will be the resulting time patterns of sea level rise?*
  - *How are alpine glaciers 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?*

SOCIETAL CHALLENGES AND WHAT A NASA-ISRO SAR COULD CONTRIBUTE

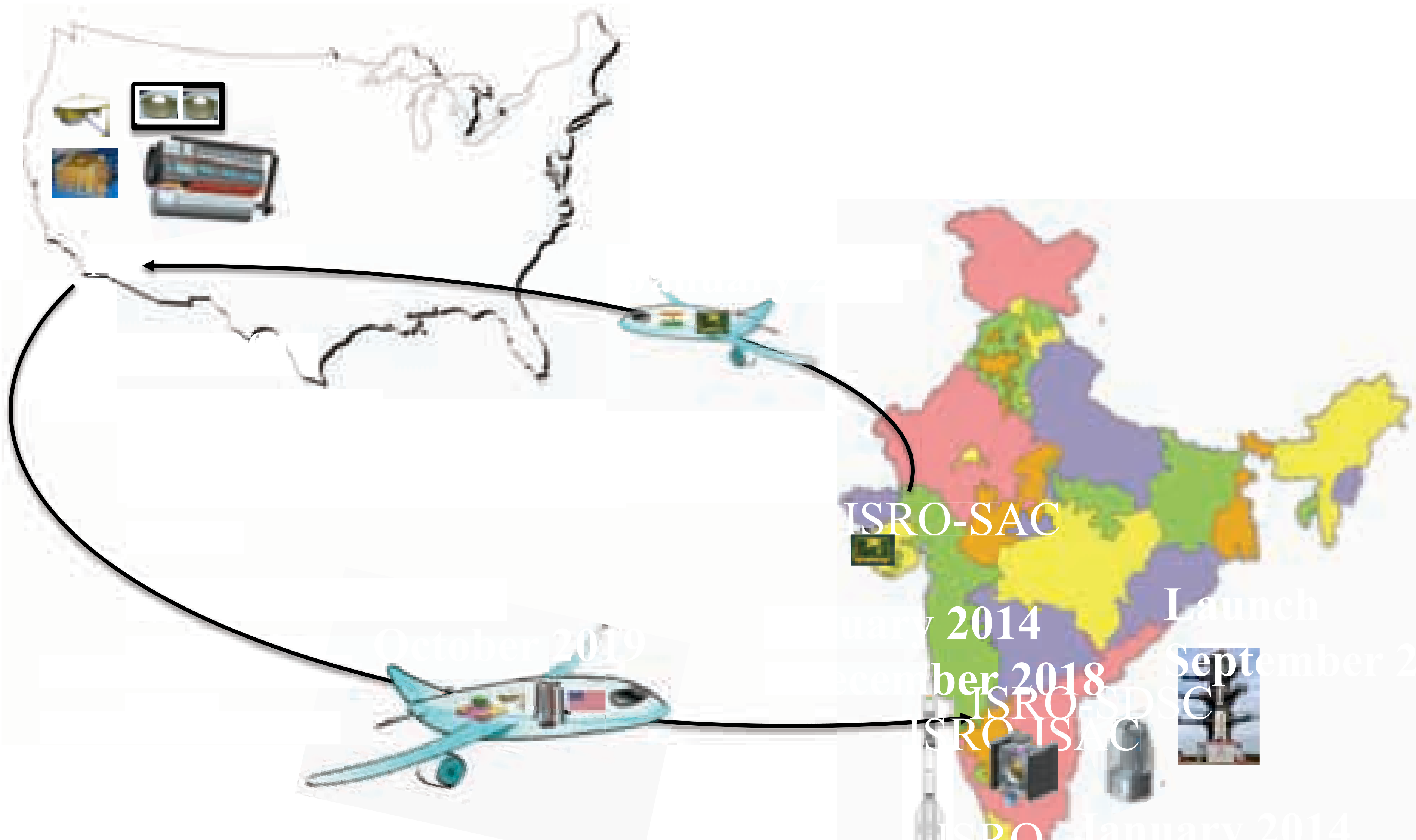
Challenge	SAR Benefit Through Regular Monitoring of:
Global Food Security	- Soil moisture and crop growth at agricultural scale - Desertification at regional scales
Freshwater Availability	- Aquifer use/extent regionally - Water-body extent changes - Glaciers serving as water sources
Human Health	- Moisture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

ISRO-NASA Work Share

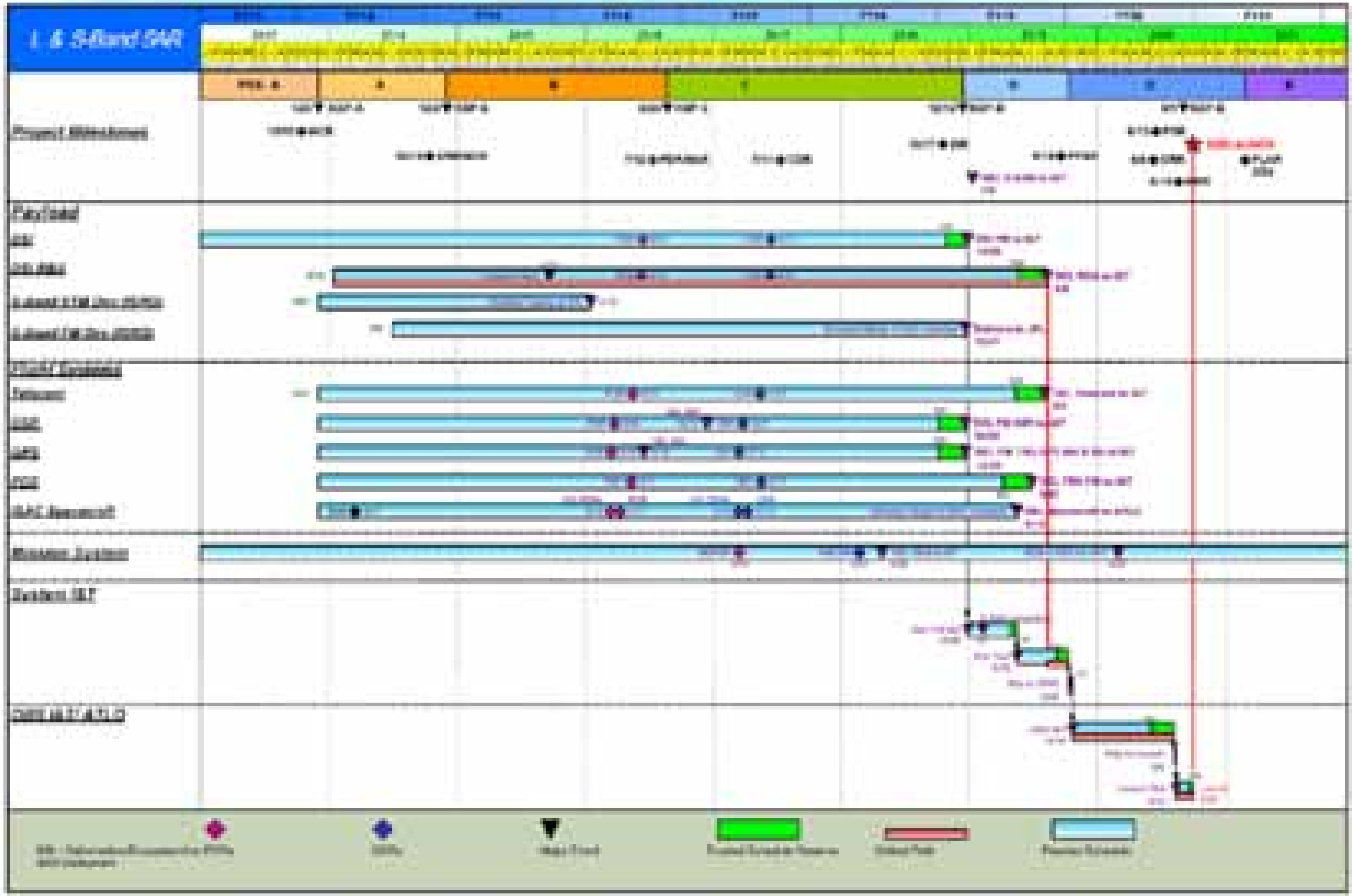




Observatory Development Flow



Project Schedule



Challenges

Technical Challenges
- Project size and Scope
- S/C & LV dedicated to a single large payload
- Operational complexity
- Large Data volume and downlink

Process Challenges
- Joint processes needed in system and interface engineering
- Maintain own internal processes for each organization
- Documentation, Reviews, Schedule

Logistic and Cultural Challenges
- Time Differences of 12.5 to 13.5 hours
- Cultural norms
- Language
- Travel constraints
- Use non-travel communication means like videocon, webex etc

Summary

- NI-SAR mission is a major Earth science/ application mission with substantial societal benefits
  - The NI-SAR mission will be the world's first dual frequency (L-and S-band) SweepSAR mission.
  - Innovative collaboration with ISRO has enabled this exciting mission concept.
  - Both parties are keen on the win-win mission collaboration
- ISRO & NASA are in a strong position to take the collaboration to the next level of formulation and implementation.
- Recent collaborations have helped form the basic relationship between the two organizations for future
- Both agencies should get the public involved through outreach activities and public education
  - Will inspire the young generation to take up science & technology as a viable career

Monitoring The Changing Earth From Space

A Joint NASA-ISRO Radar Mission Concept for a Dynamic Planet

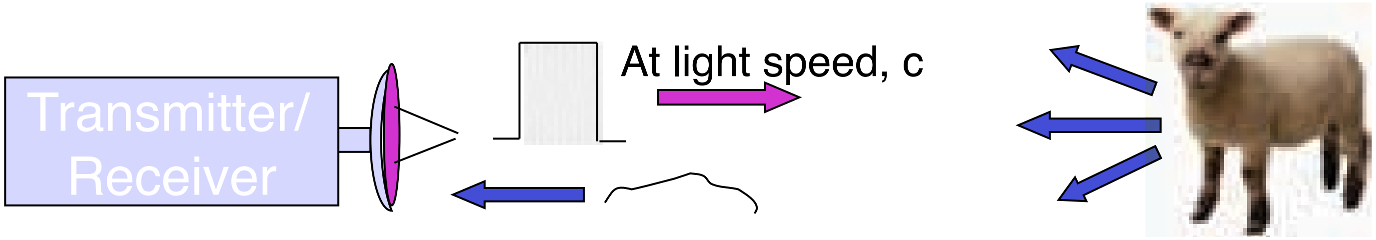
Paul A. Rosen
Jet Propulsion Laboratory
California Institute of Technology

November 24, 2013

Monitoring the Changing Earth from Space
Outline

- A bit of background on the speaker and on radar
- Introduction to the development of radar at JPL
- Video introducing the NASA-ISRO radar mission concept
- Science/Applications benefits to society
- Mission design and other cool stuff
- Conclusion

The Radar Remote Sensing Concept



Object scatters energy back to radar

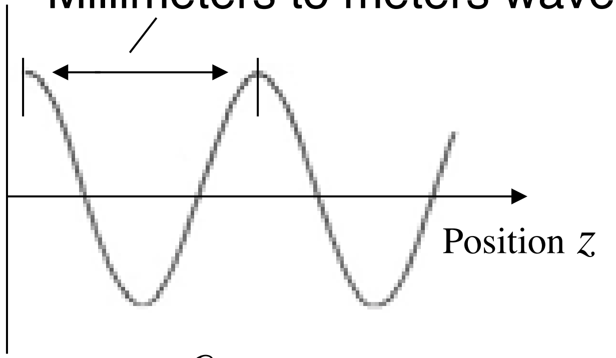
- Much like sound waves, radar waves carry information that echoes from distant objects
- The time delay of the echo measures the distance to the object
- The changes of the message in the echo determine the object characteristics

Why Radar Remote Sensing?

- Why Remote Sensing?
  - Area too large, inaccessible or hazardous for *in situ* observation
  - Sensitive to aspects of the environment that elude our senses
  - Efficient, quantitative monitoring of changes to the environment either from natural or anthropogenic causes
- Why Radar Remote Sensing?
  - We control the source, so we can select what we observe
  - Sees through clouds
  - Sees at night
  - Sensitive to the geometric and electrical properties of objects rather than chemical constituents

Radar and Light Waves

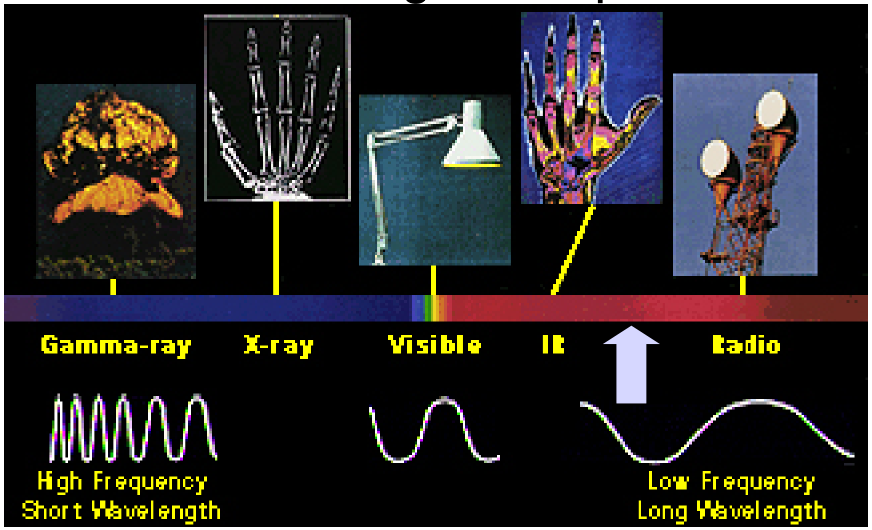
Millimeters to meters wavelength



$$\lambda = \frac{c}{f}$$

- Radars operate at microwave frequencies, an invisible part of the electromagnetic spectrum
- Microwaves have wavelengths in the millimeter to meter range
- Like lasers, radars are coherent and nearly a pure tone

The Electromagnetic Spectrum



tiny 100's μm mm's to m's

Common Radar Frequency Bands

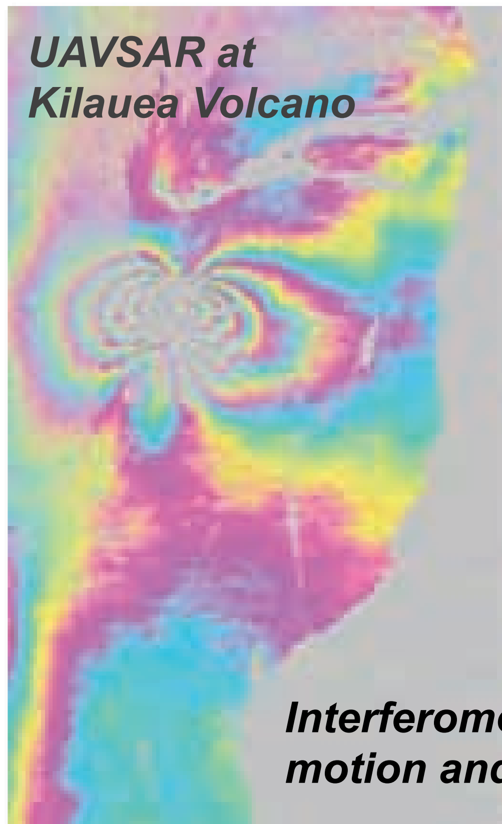
Band	Ka	Ku	X	C	S	L	P
Wavelength (cm)	1	2	3	6	12	24	75
Frequency (G-cycles/s)	30	15	10	5	2.5	1.2	0.4

SAR Extends Imagery Beyond the Visible Spectrum

SAR observations allow us to experience the Earth in a fundamentally different light, day or night, independent of cloud cover

SIR-C over Africa

Polarization and frequency diversity to characterize surfaces and measure moisture



UAVSAR at Kilauea Volcano

Interferometry to measure motion and surface change

SIR-A over Northwest Sudan: Selma Sand Sheet

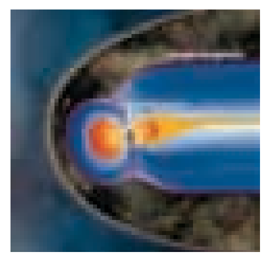
What do we want to measure with radar?

- Topography
- Geography
- Chemistry
  - Composition
  - Phase
- Dynamics
  - Thermo-
  - Hydro-
  - Geo-
  - Bio-

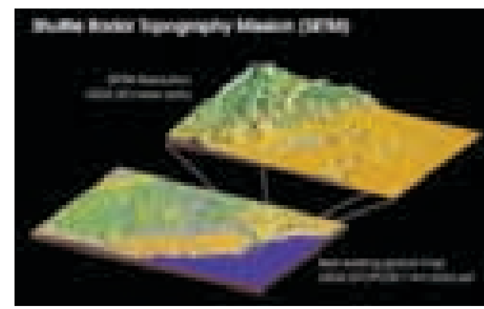
Rosen and Radar

NASA Voyager Mission Studies of Saturn’s rings

JAXA-ISAS Akebono Aurora Studies Mission

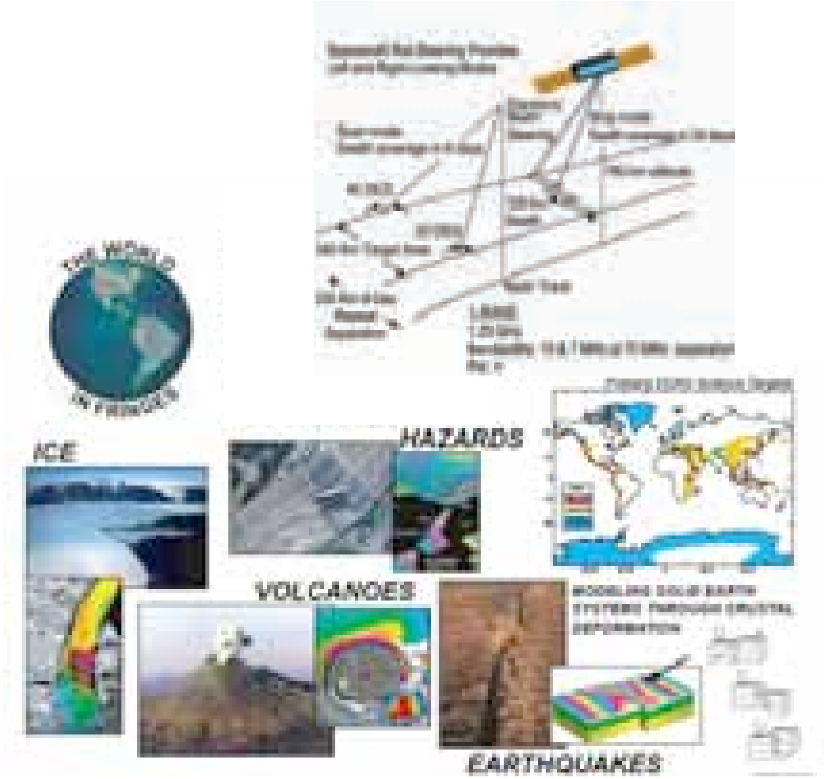


NASA Shuttle Radar Topography Mission



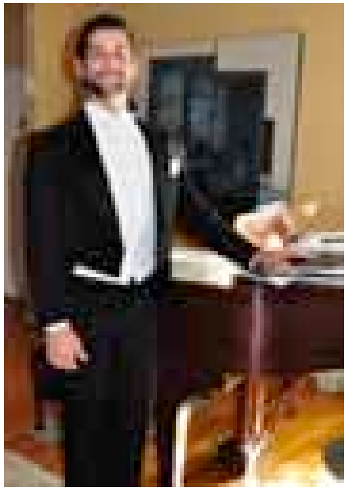
Rosen and Radar

Studies of Earth motion using radar



In my spare time, with my wife, …

… raising a family …



… and recently cooking Indian cuisine

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: Galex 2003 MMM 2008 Diviner 2009 Kepler 2009 Herschel 2009

Explorer 1-5
1958
Van Allen Belts

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

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

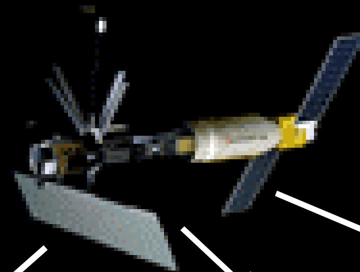
Infrared Sat
1983
Telescope

Magellan
1989
Venus Radar

Galileo
1989
Jupiter

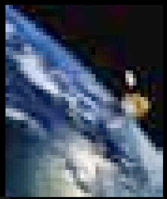
Mars Observer
1992
Mars Orbiter

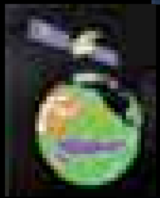
How it began in Space … The Legacy of SeaSat



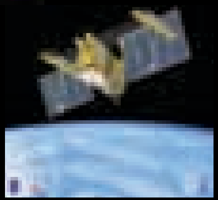
ALTIMETER

TOPEX / Poseidon (1992)





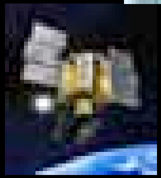
Jason -1 (2001)



Ocean Surface Topography Mission: (2008)

SCATTEROMETER

NSCAT (1996)



QuikSCAT (1998)

SeaWinds (2002)

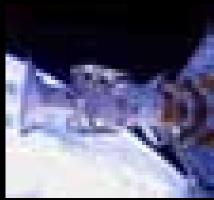
Ocean Vector Wind Measurement: (~2014)

RADIOMETER

Sea Surface Salinity: Aquarius (2009)

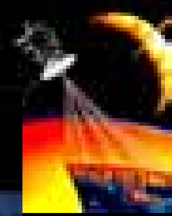
Soil Moisture & Freeze/Thaw: SMAP (~2015)

SYNTHETIC APERTURE RADAR



SIR -A (1981)
SIR -B (1984)
SIR -C (1994)

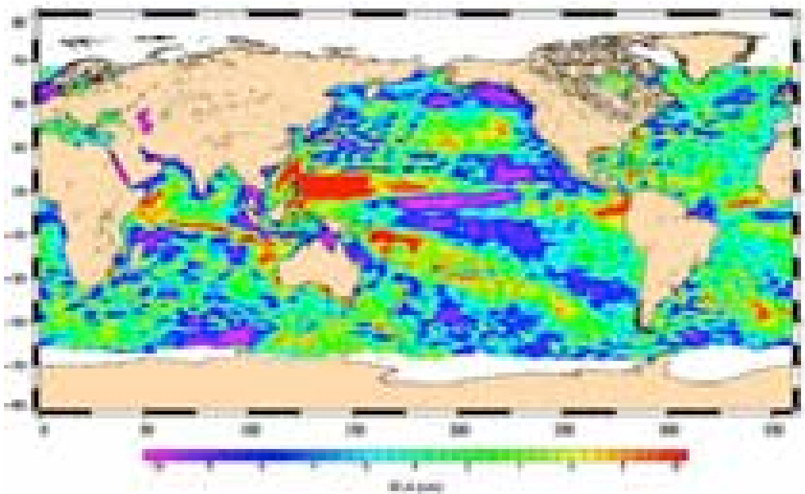
Magellan (1989)
Cassini (1997)



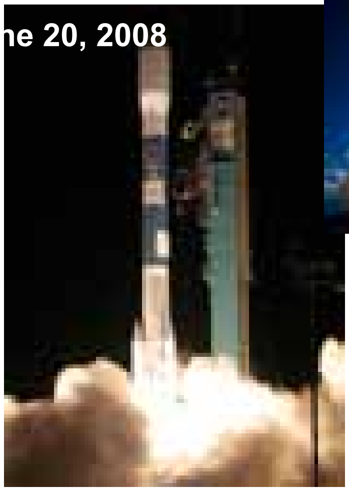
SRTM (2000)

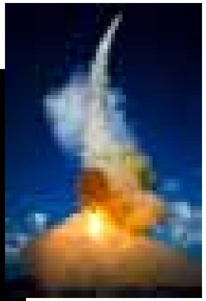
L-Band InSAR (Proposed)

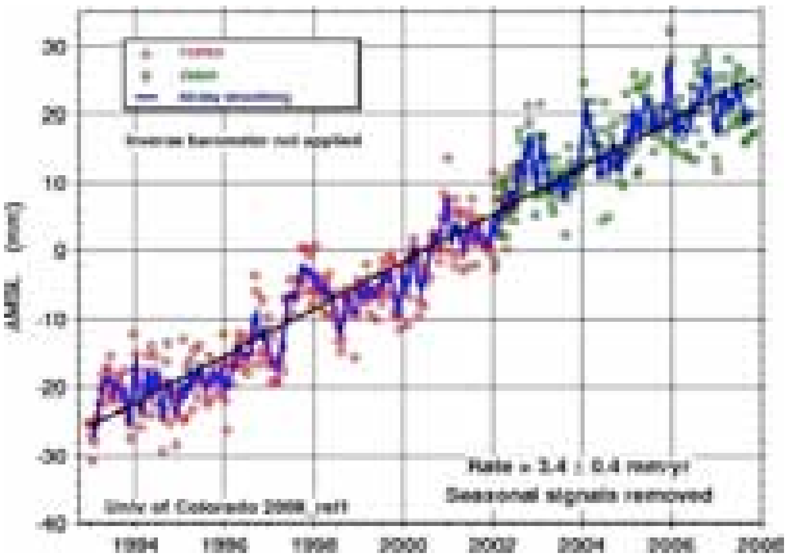
TOPEX-Jason 1-OSTM Altimetry



Less than a month after launch, the NASA-French space agency Ocean Surface Topography Mission (OSTM)/Jason 2 oceanography satellite produced its first complete maps of global ocean surface topography, surface wave height and wind speed



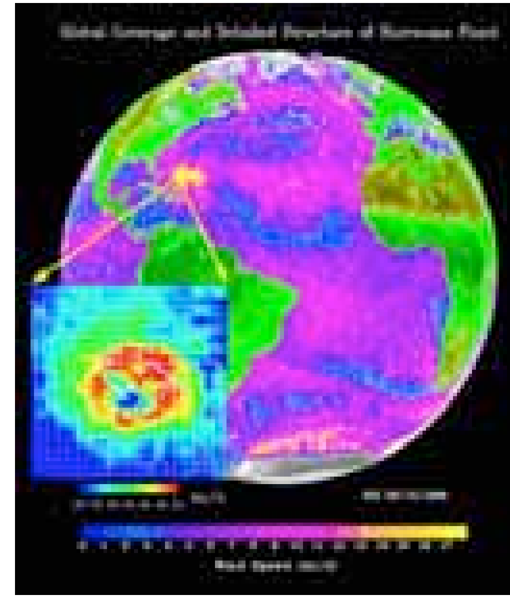




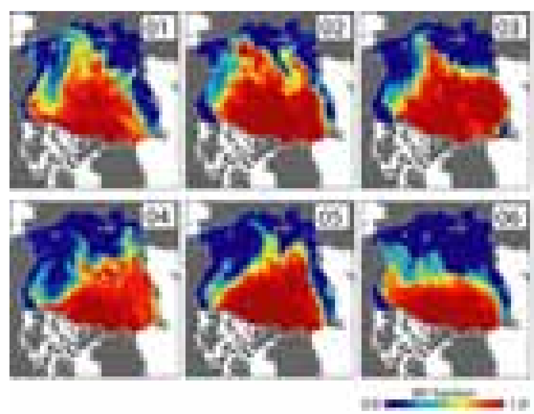
Scatterometers for Ocean Wind

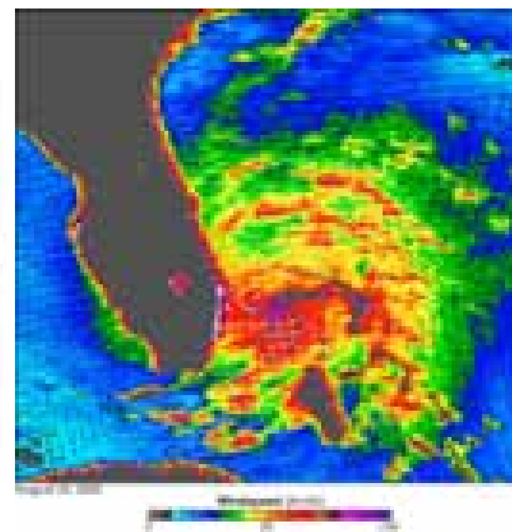
- *Scatterometers* are radar instruments that measure the reflective properties of the Earth's surface
- Winds roughen the sea, so radar reflectivity can be used to estimate wind speed
- Also useful for ice tracking, ice melting, salinity, soil moisture and other applications

Seawinds on QuikSCAT



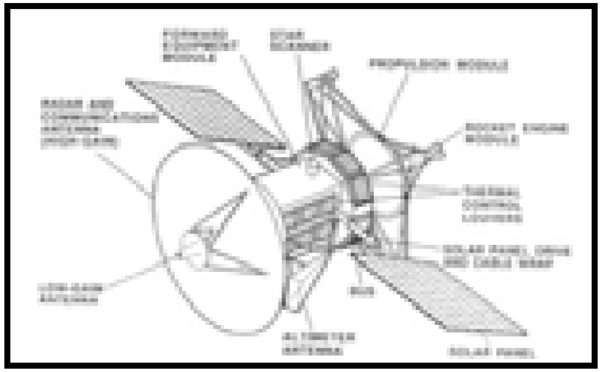
Future Mission: Dual-frequency concept

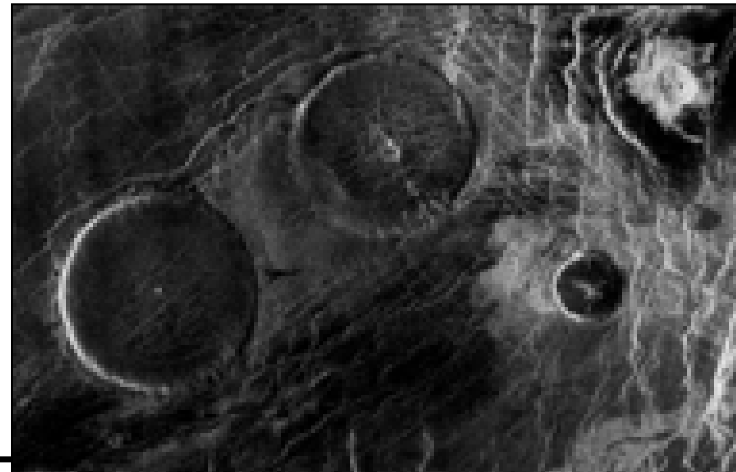


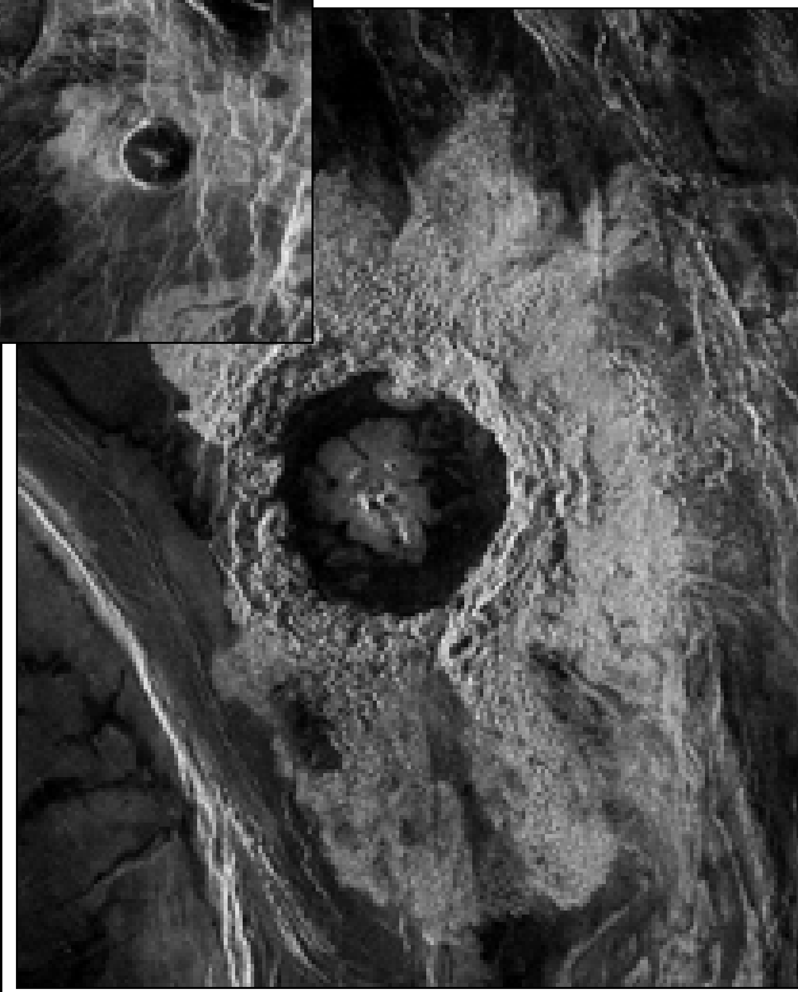


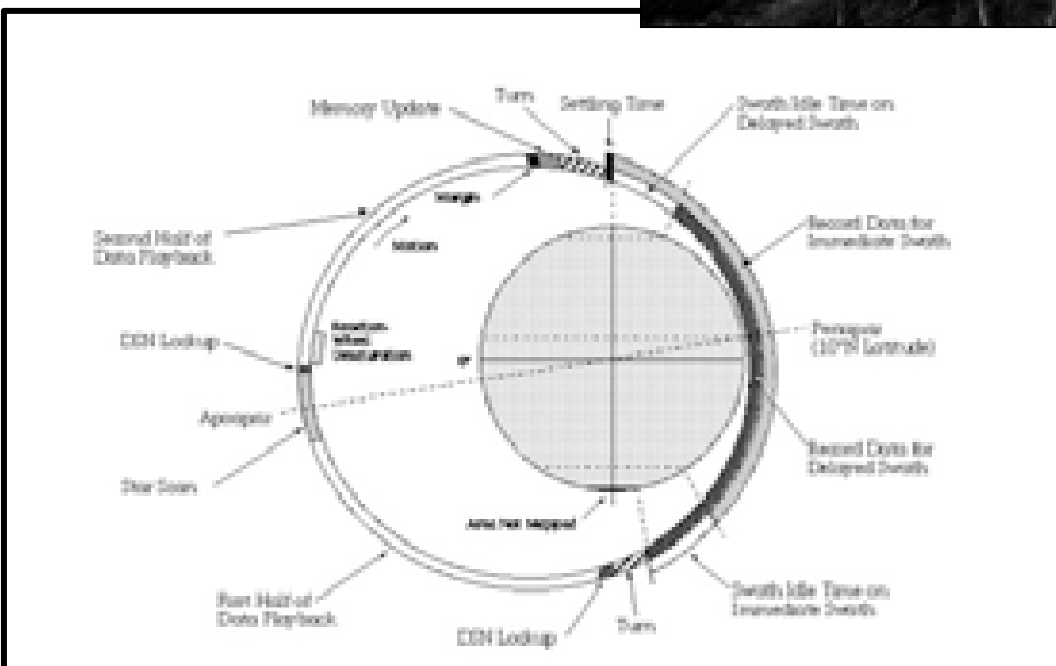
Magellan Radar Mission to Venus

Radar **to image through clouds**

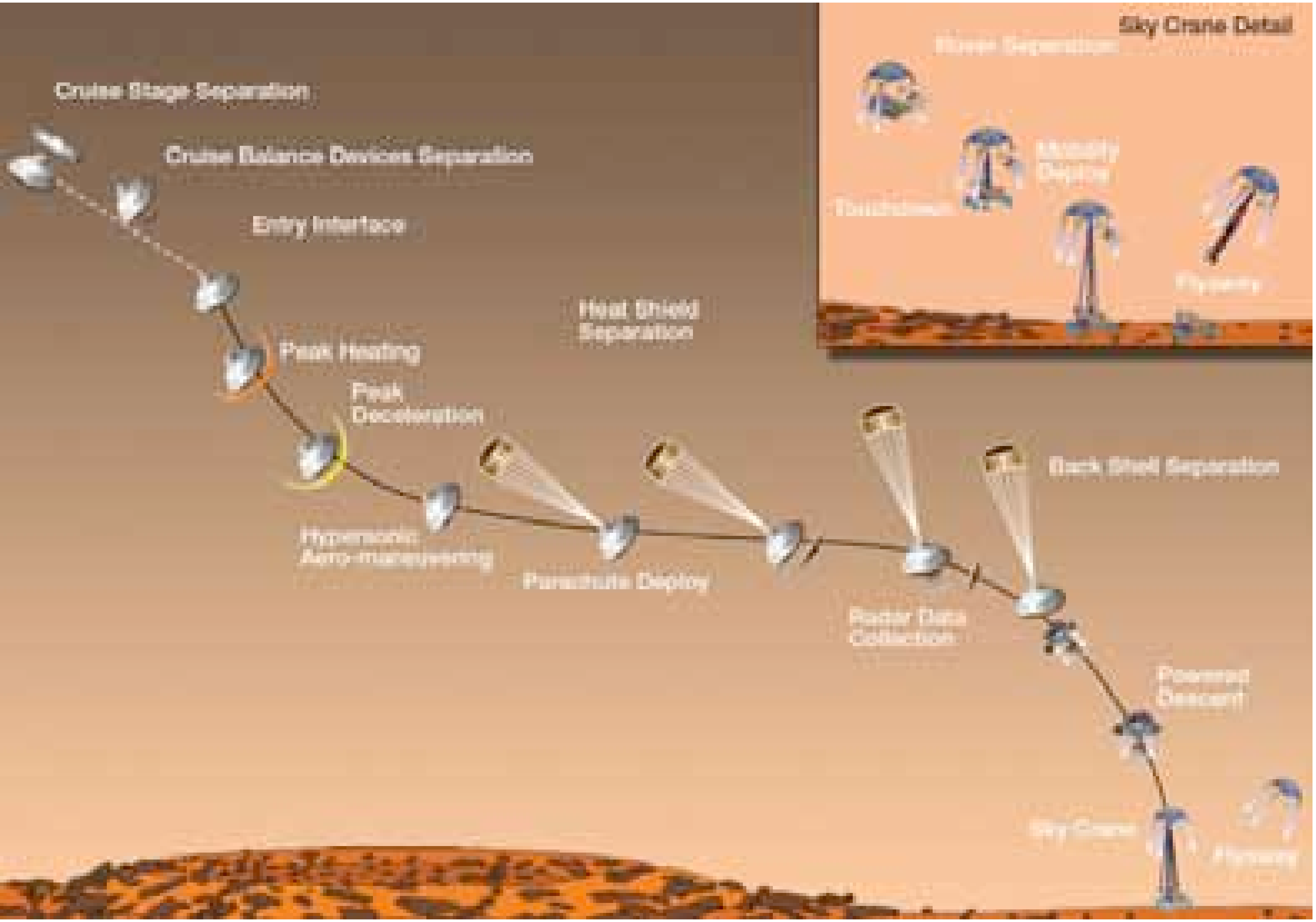








Timeline of Major Mission Events During Curiosity's August 5, 2012 Landing



Time Event Occurrence Received on Earth (PDT)

[10:24:33.8 PM] Atmospheric Entry

[10:28:53.0 PM] Parachute Deploy

[10:29:12.7 PM] Heat Shield Separation

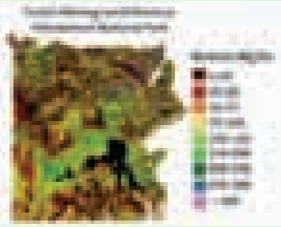
[10:31:26.7 PM] Rover Separation (from Descent Stage)

[10:31:45.4 PM] Touchdown

Introduction to Monitoring the Changing Earth

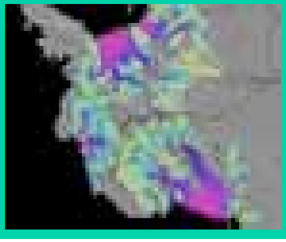
Science & Applications to Implementation

Ecosystems



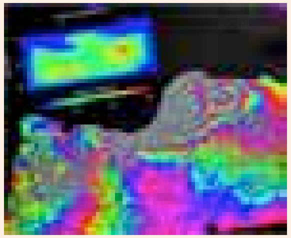
- Biomass, disturbance,
- Effects of changing climate on habitats and CO_2
- Agriculture

Ice Dynamics



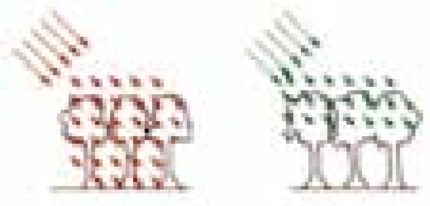
- Ice velocity, thickness
- Response of ice sheets to climate change & sea level rise

Solid Earth



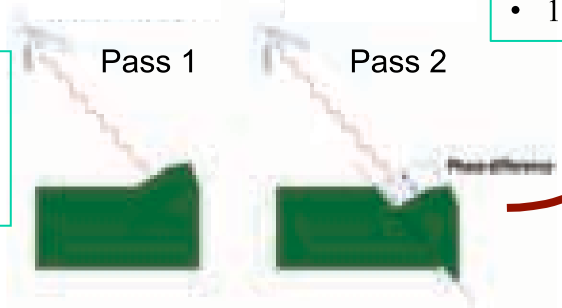
- Surface Deformation,
- Hazards Response,
- Water Resource Management

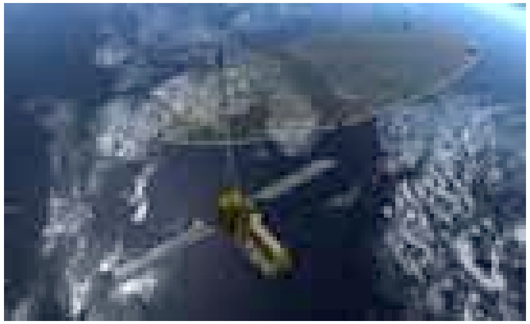
L- and S-band Wavelength



Polarimetry

Repeat Pass InSAR

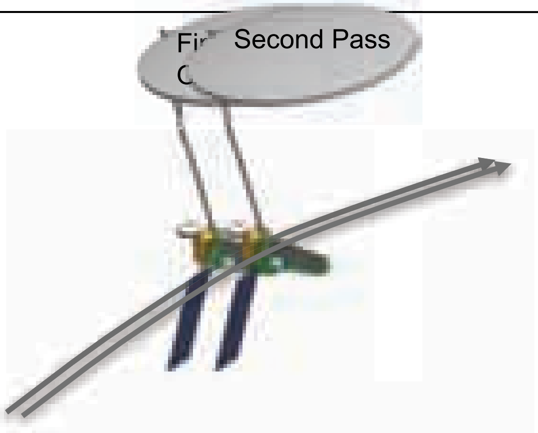


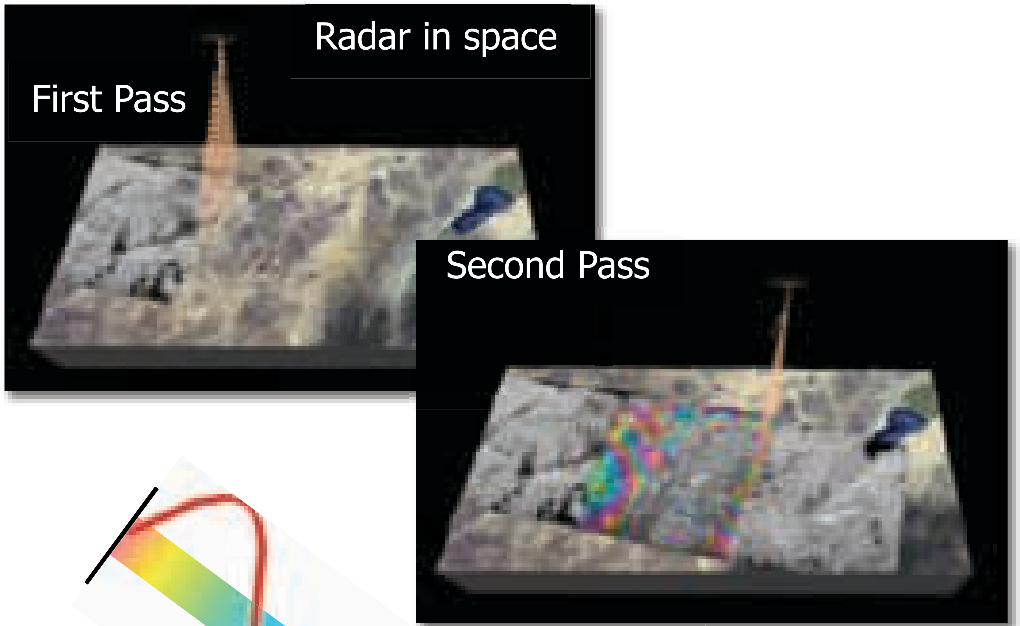


Mission Concept:

- L- and S-band SweepSAR with a large reflector
- 747km altitude, circular, 98 degrees inclination, sun-synchronous, dawn-dusk (6 AM-6PM)
- 12-day repeat

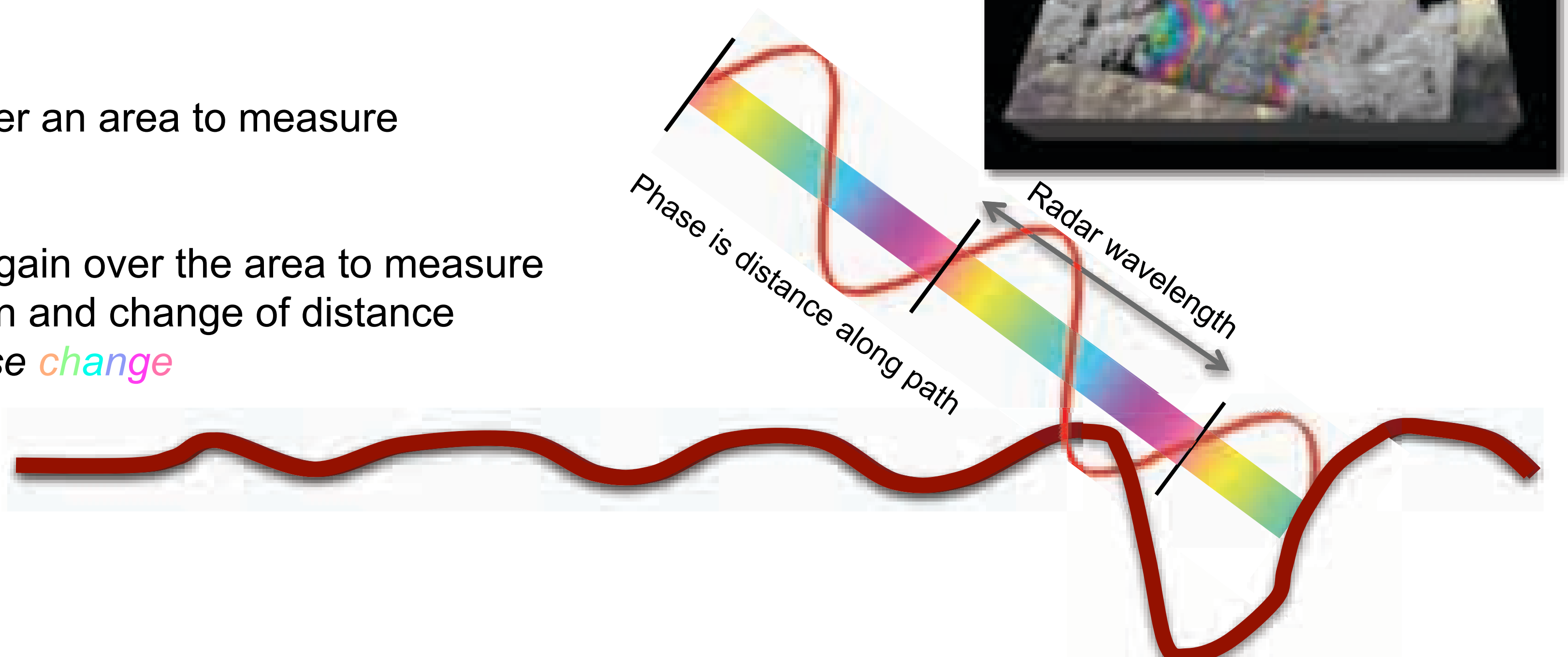
Interferometry for Measuring Aquifer Depletion





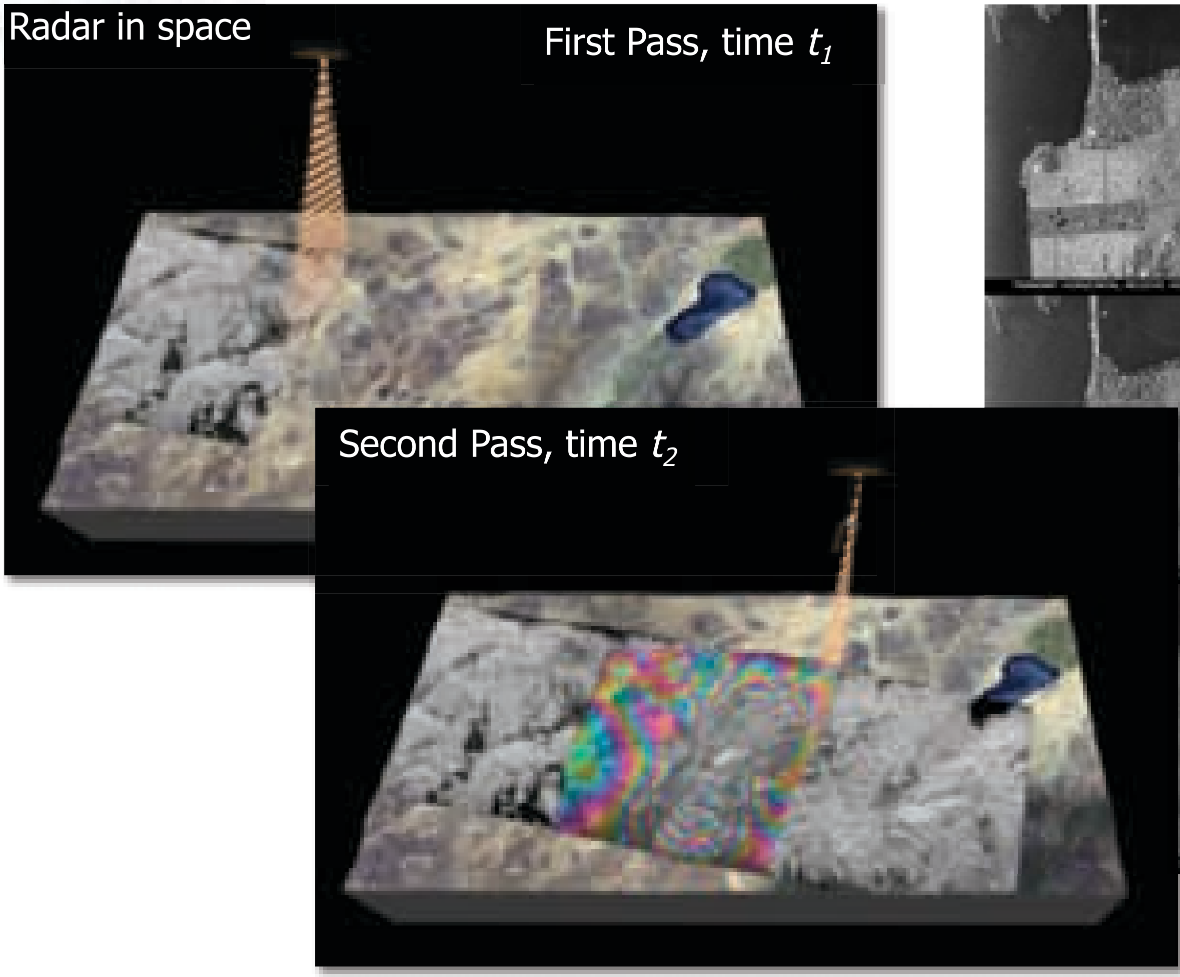
Radar flies over an area to measure reflection

Radar flies again over the area to measure new reflection and change of distance through *phase* change

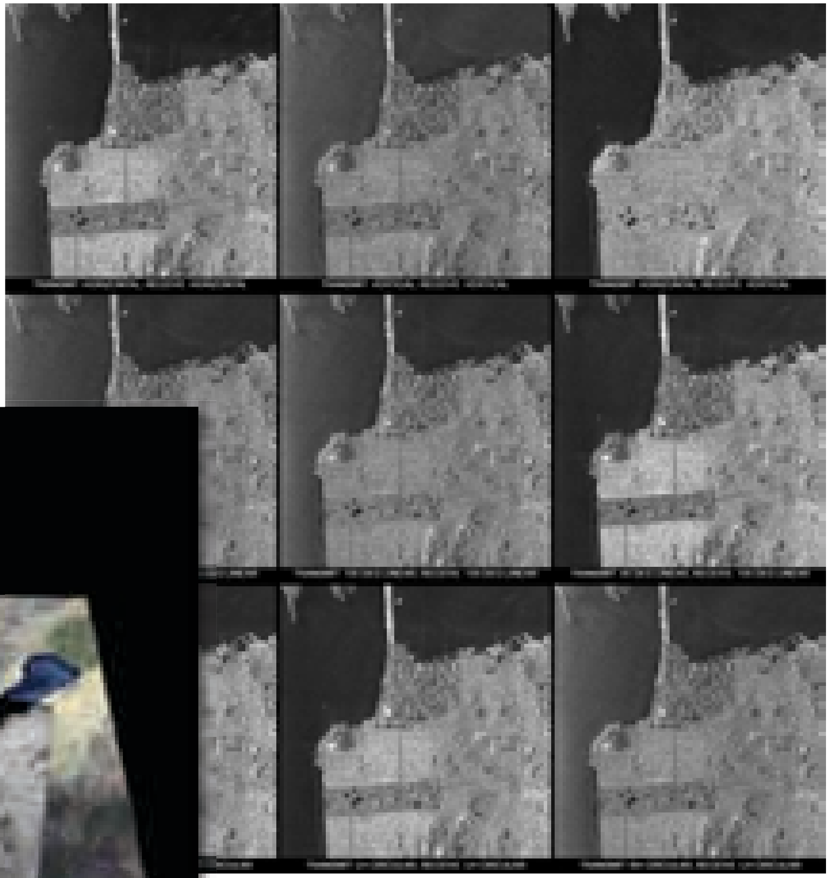


NI-SAR Measurements to Achieve Science Objectives

Repeat Pass Interferometry

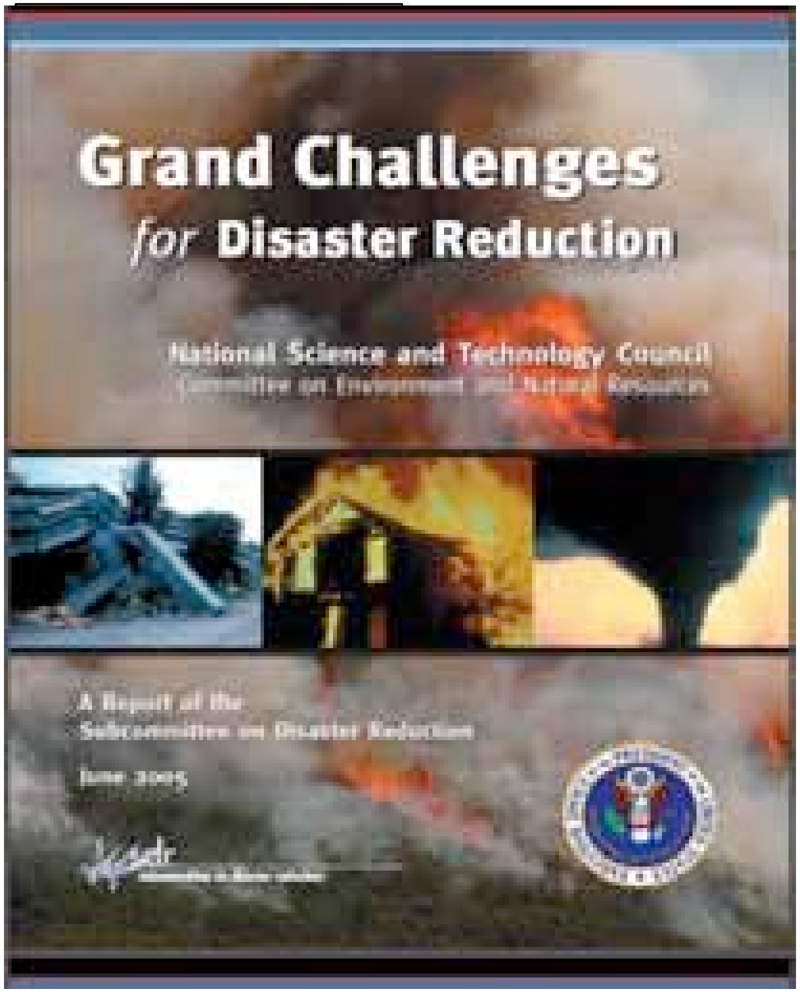


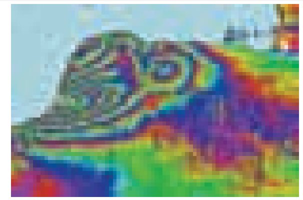
Polarimetric Diversity



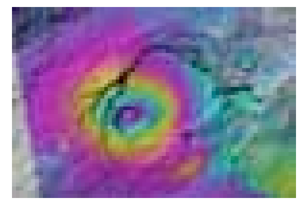
US and India Share Many Common Goals in Disaster Reduction and Mitigation

NI-SAR will support 9 of the 13 identified *Grand Challenge* hazards

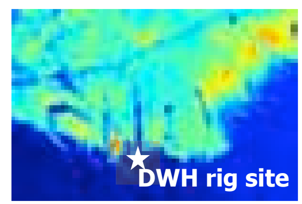




Earthquakes

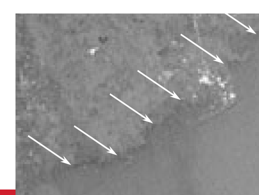


Volcanoes



Anthropogenic-Technological Disasters

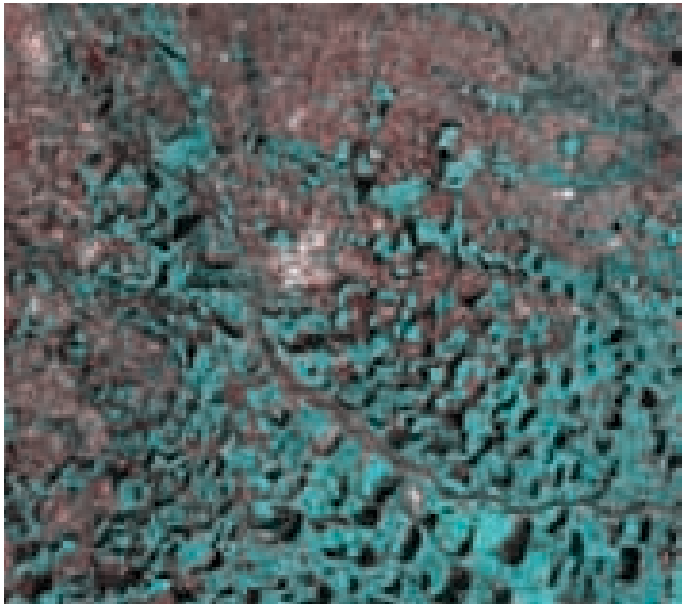
Floods



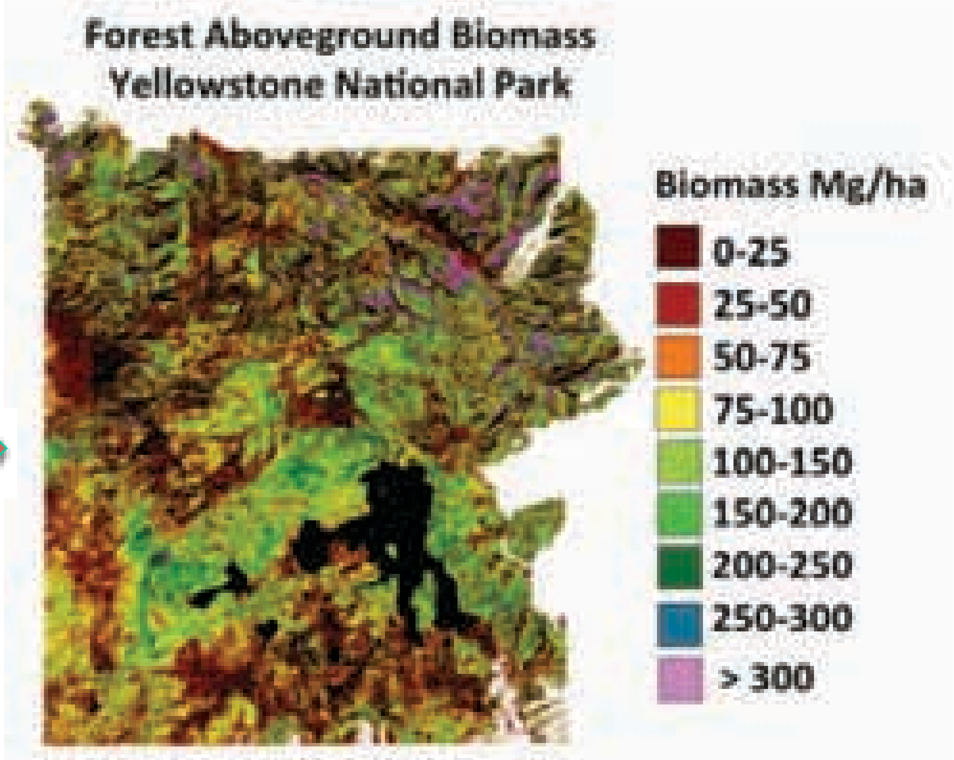
Coastal Inundation

NASA-ISRO SAR Mission Extends India's Science and Applications Programs

- RISAT-1, India's first SAR Mission, is best suited to monitoring light (low biomass) crops.
- The NASA-ISRO SAR Mission extends these capabilities to heavier crops and regenerating forests



RISAT-1 C-band Two-date composite of Sivaganga Area of Tamil Nadu showing Samba rice area (cyan colour)



NASA-ISRO L/S-band SAR Mission would enable higher density biomass estimates

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

- *Global* L-band data with unprecedented spatial and temporal sampling will drive new directions in science and applications
- *Globally distributed but targeted* S-band data for science applications would be a fundamentally new data set

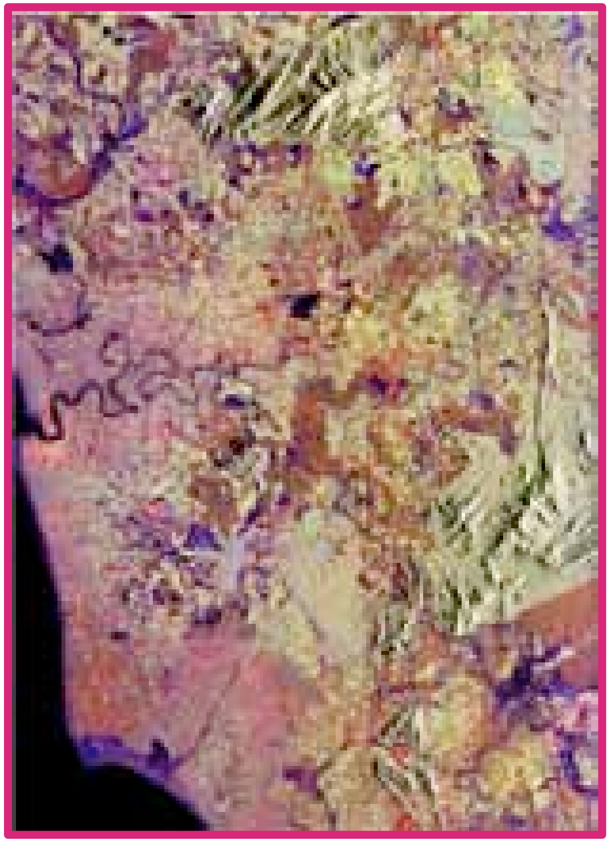
Wheat Fields,

Dnieper River, Ukraine

Red: LHH
Green: LHV
Blue: CHV

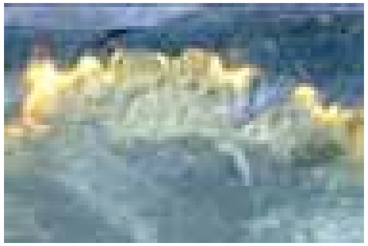
Rubber, banana, and oil palm trees,

Muar, Malaysia



The NASA-ISRO SAR Mission Captures the Earth in Motion



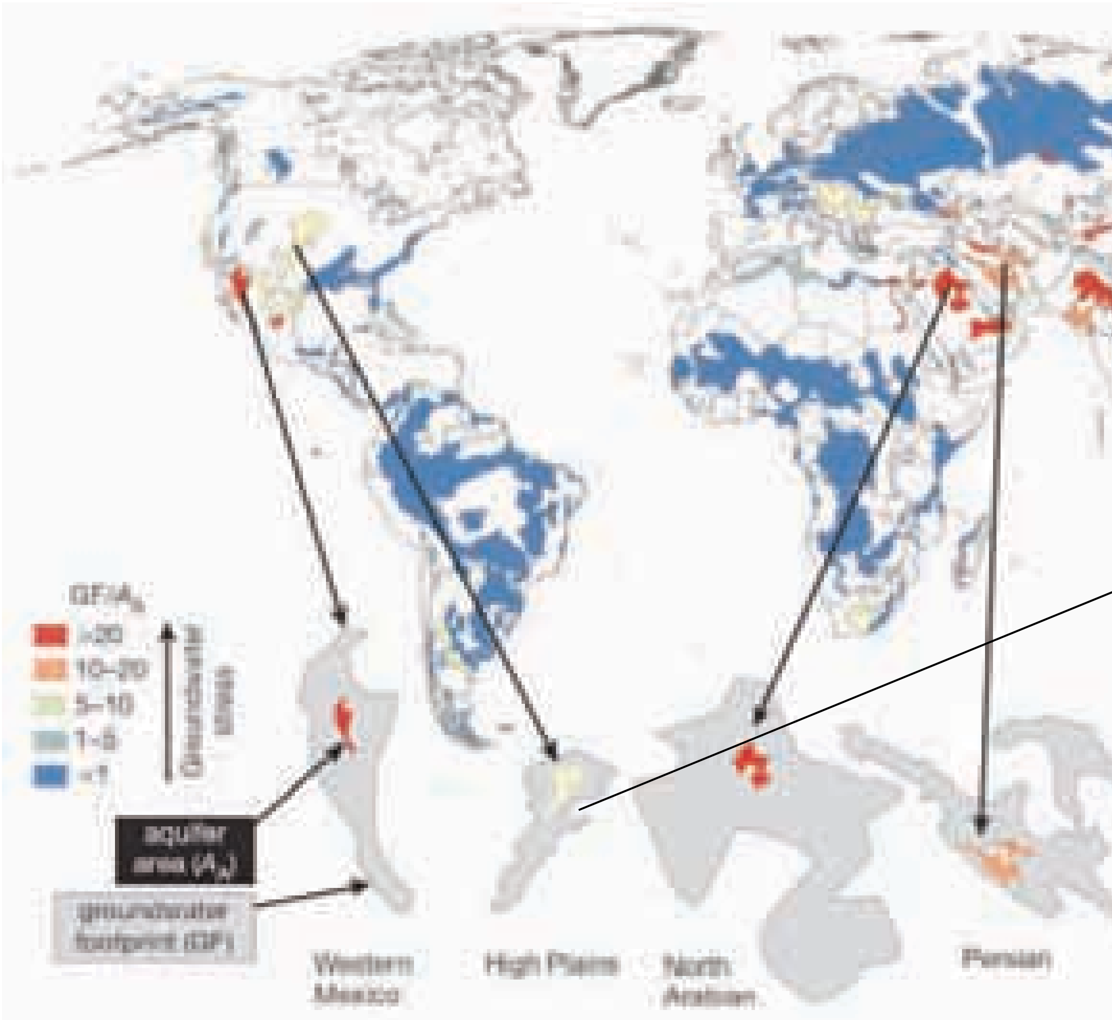


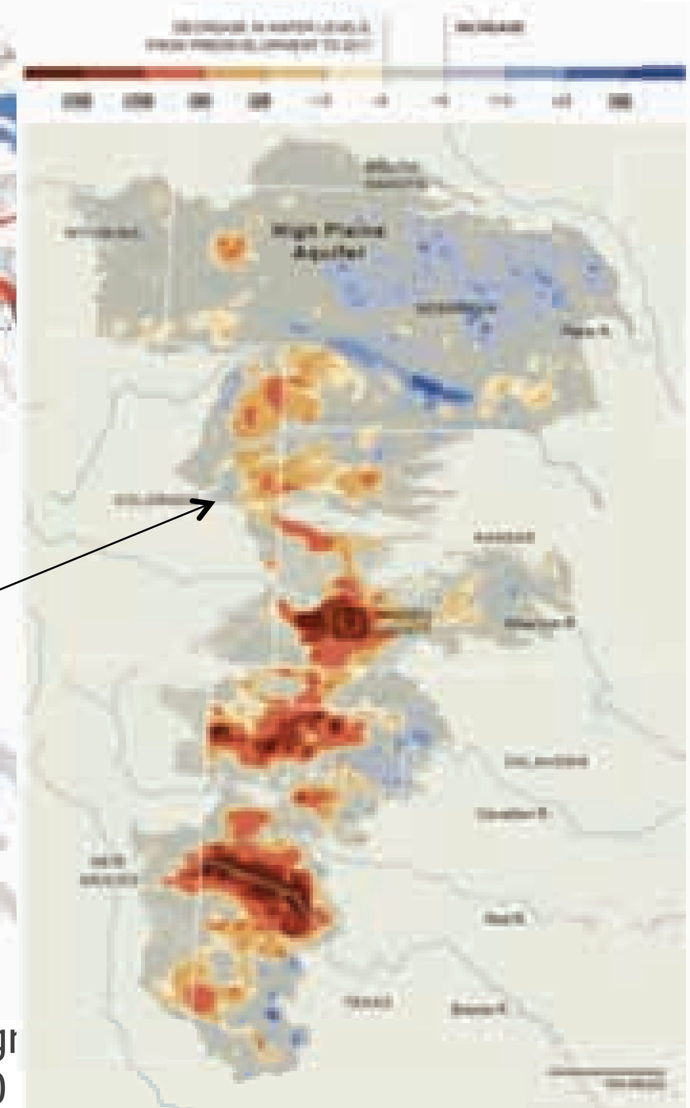

- *Dense temporal and spatial sampling*
  - Reveals the mechanisms that drive poorly understood surface processes
    - Fast-transients on Ice sheets and glaciers
    - Disturbance and recovery in forests
    - Tracking evolving hazards
- C*omprehensive* global measurements
  - Of ice to improve climate 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

Societal Challenges and What a NASA-ISRO SAR Could Contribute

Challenge	SAR Benefit Through Regular 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

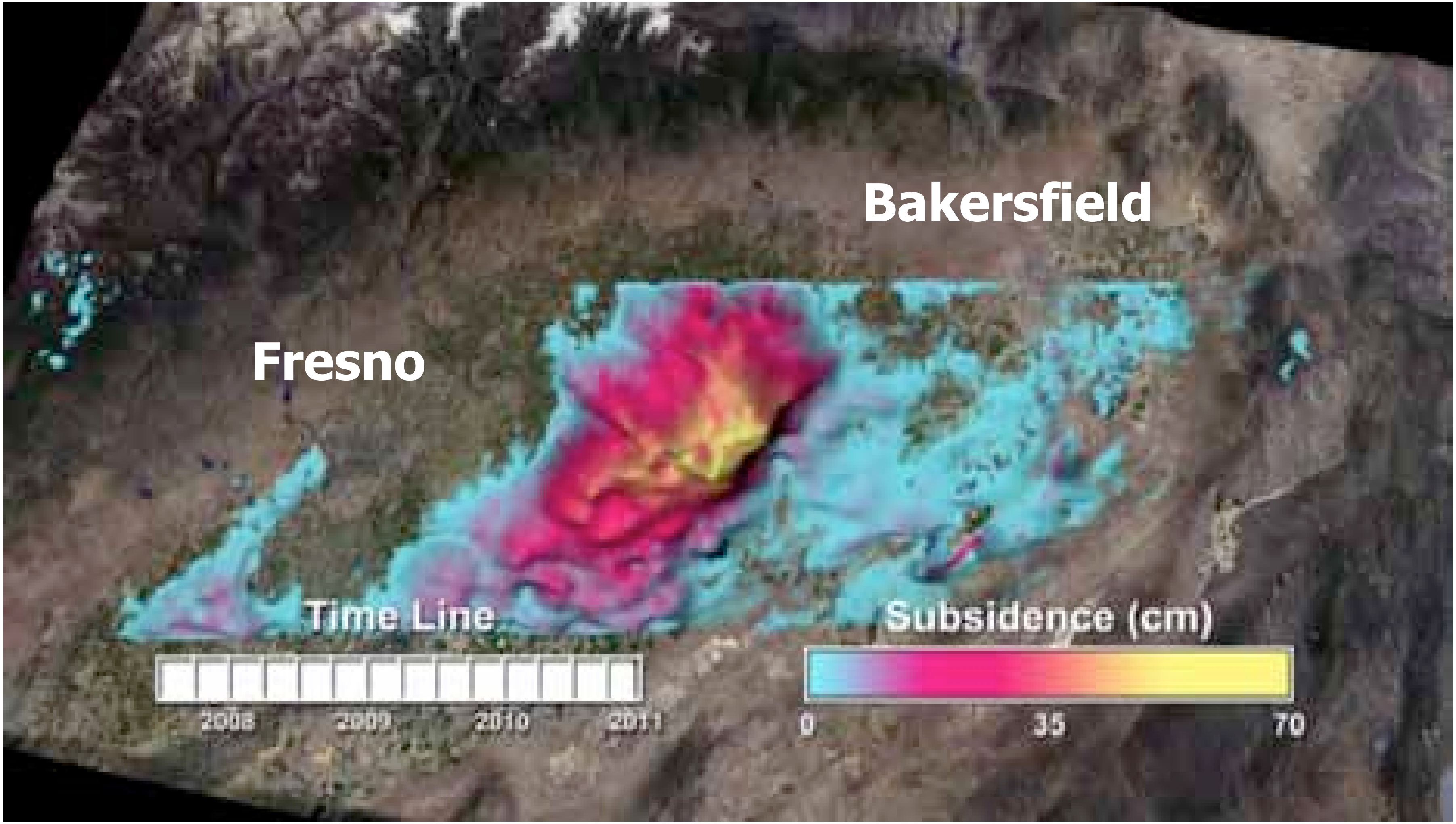
Locations of the World’s Aquifers





“Water balance of global aquifers revealed by gr
Gleeson, T., et al. (2012) Nature 488, 197–200

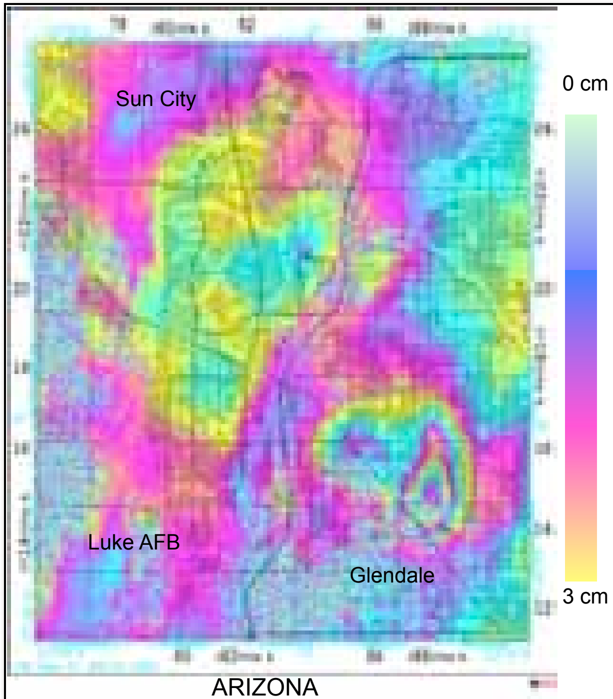
Measured Aquifer Depletion with Radar Time Series



Credits: InSAR analysis – Zhen Liu, Tom Farr (JPL); Visualization – Vince Realmuto (JPL) http://photojournal.jpl.nasa.gov/catalog/PIA16293

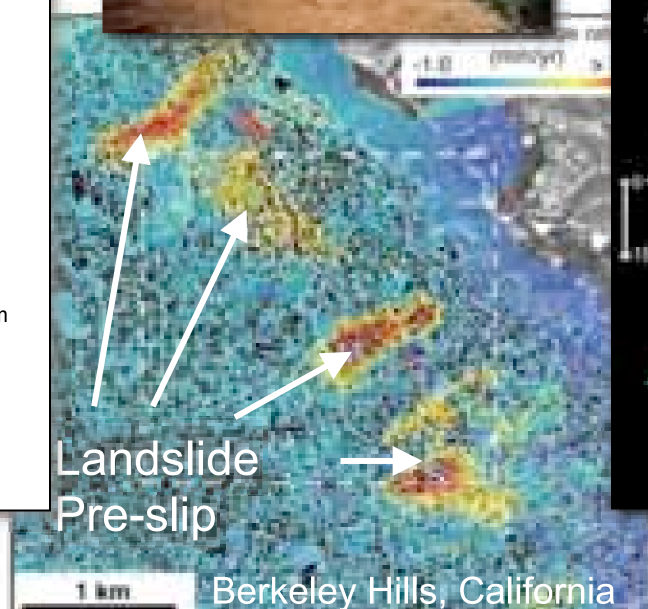
Subsurface Reservoirs & Subsidence

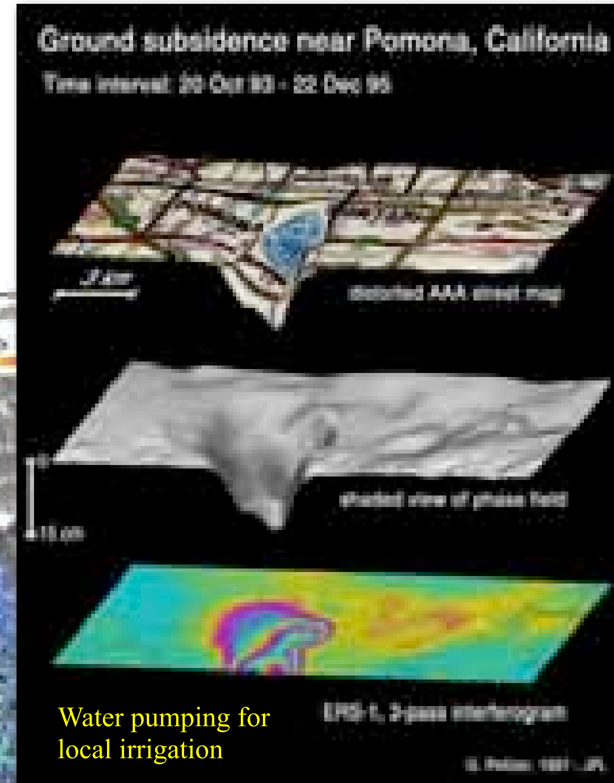
Water, Oil and Gas Resource Usage, Carbon Sequestration



Produced by Vexcel Corporation under NASA's State & Local Partnership Program, John C. Stennis Space Center.

Water pumping for local irrigation





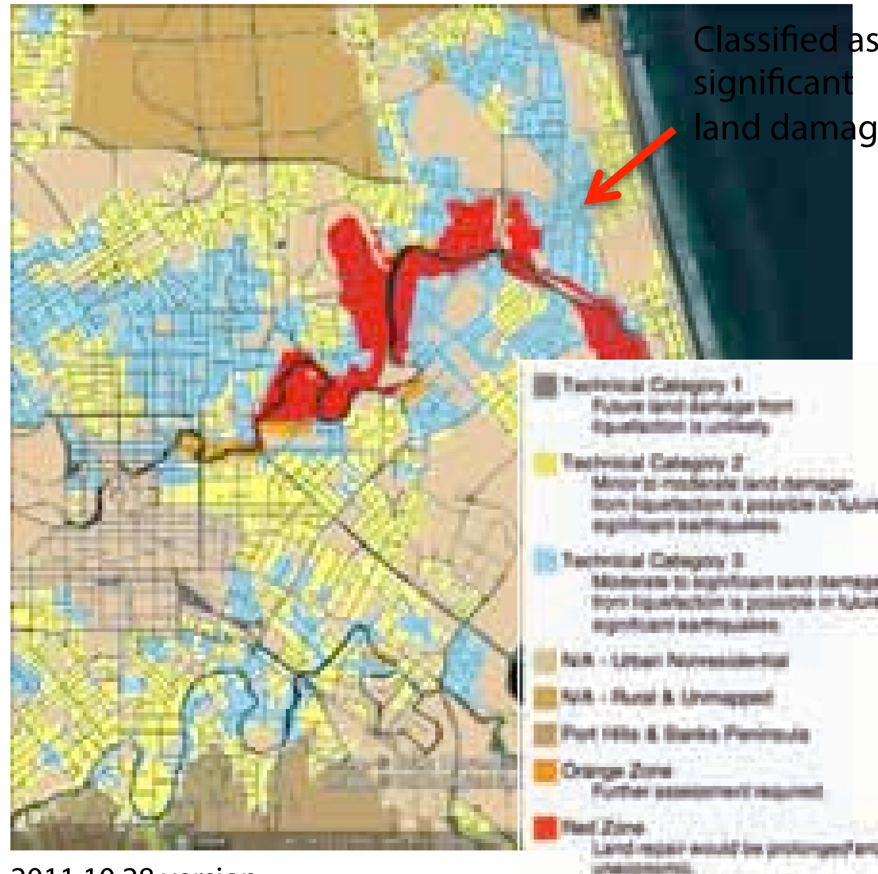
- ***Radar can measure surface deformation over wide areas to characterize what is happening at depth and on the surface – withdrawal or replenishment of fluids and landslides – to provide new information to resource planners where little data exists at the regional scale.***

Radar Derived Damage Proxy Map vs Ground Truth

From radar data acquired **3 days** after EQ

Damage Proxy Map (ALOS PALSAR A335):
2010.10.10 – 2011.01.10 – 2011.02.25
Google Earth (GeoEye) Image: 2011.02.26

Technical Classification Map first released **8 months** after EQ



2011.10.28 version
Data provided by the New Zealand Government
http://data.govt.nz

Cliff Collapse

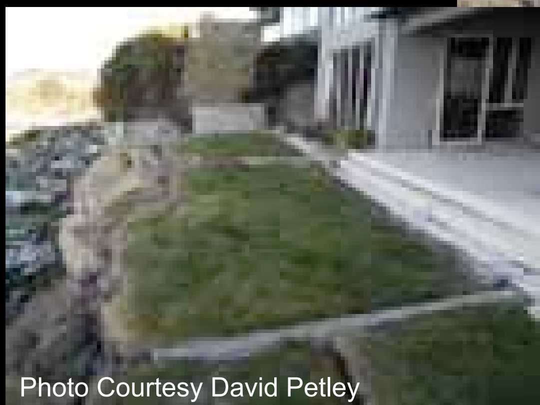
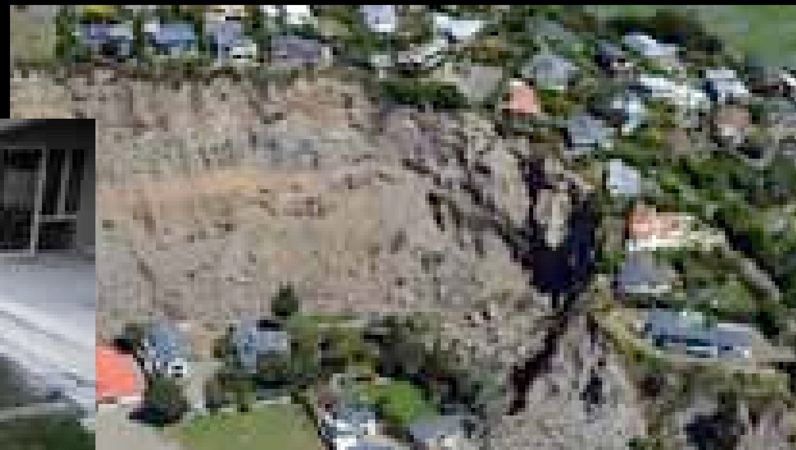
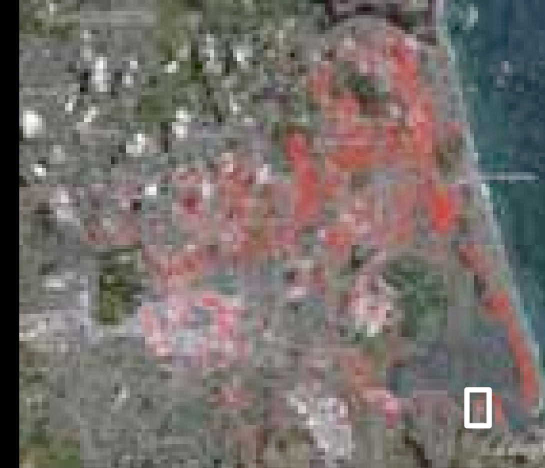


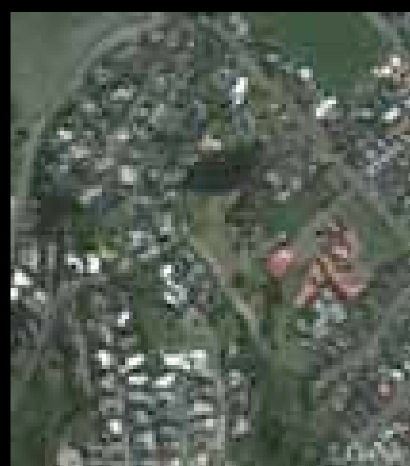
Photo Courtesy David Petley



Luxury homes teeter on the edge after huge landslides in Redcliffs, near Christchurch (Photo by Torsten Blackwood from AFP).



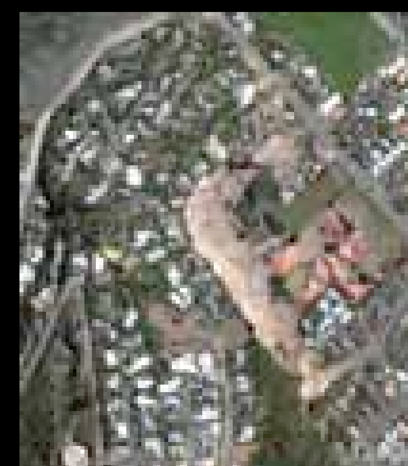
Damage Proxy Map



2010.09.03

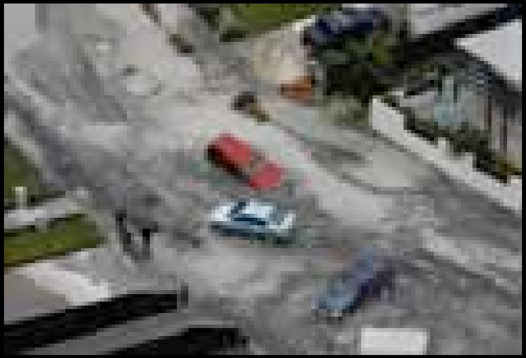
EQ M6.3

2011.02.23



2011.02.26

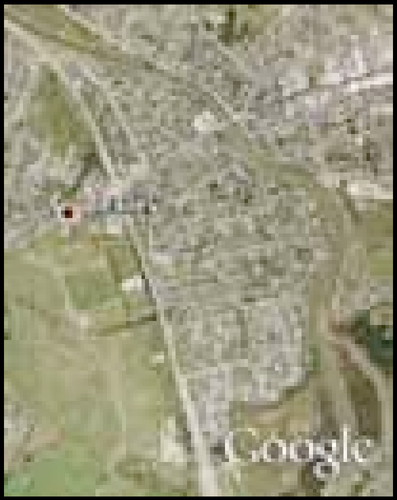
Liquefaction in Bexley



Cars stuck in the mud, Bexley
(Brett Phibbs/AFP/Getty Images)

Water Inundated Bexley (Mark Mitchell/New Zealand
Herald/Associated Press)

Damage Proxy Map

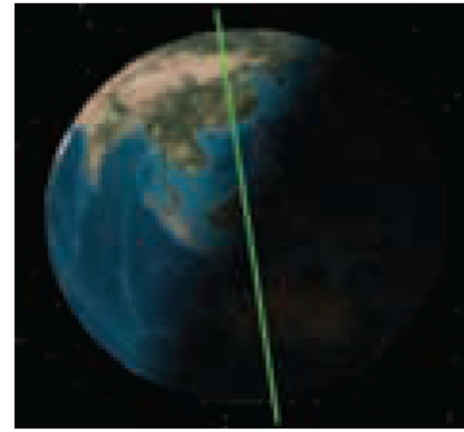


2009.03.04

2011.02.23

NASA-ISRO SAR Mission Concept

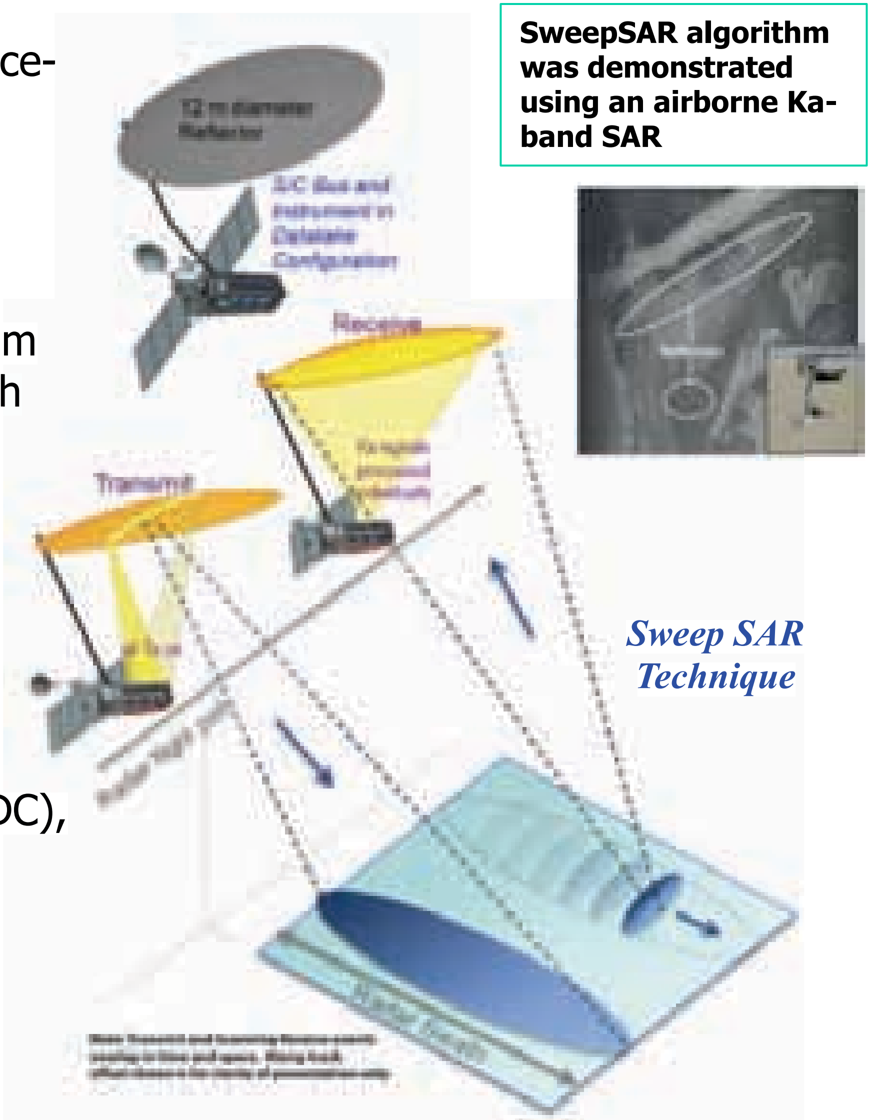
- Launch date: September 2020
- New Two-frequency L- and S-band Synthetic Aperture Radar (SAR)
- New Sweep SAR technique for rapid global data collection
- Orbit:
  - 747km altitude circular
  - 98 degrees inclination
  - sun-synchronous, dawn-dusk (6 AM – 6 PM)
  - Exact 12-day repeat within +/- 250 m
- 3 years science operations, but could last many more years
- Data are 10 m resolution or coarser, suitable for science and civilian applications
- Science data from both L- and S-band SAR will be available without any restrictions



Radar Payload Concept

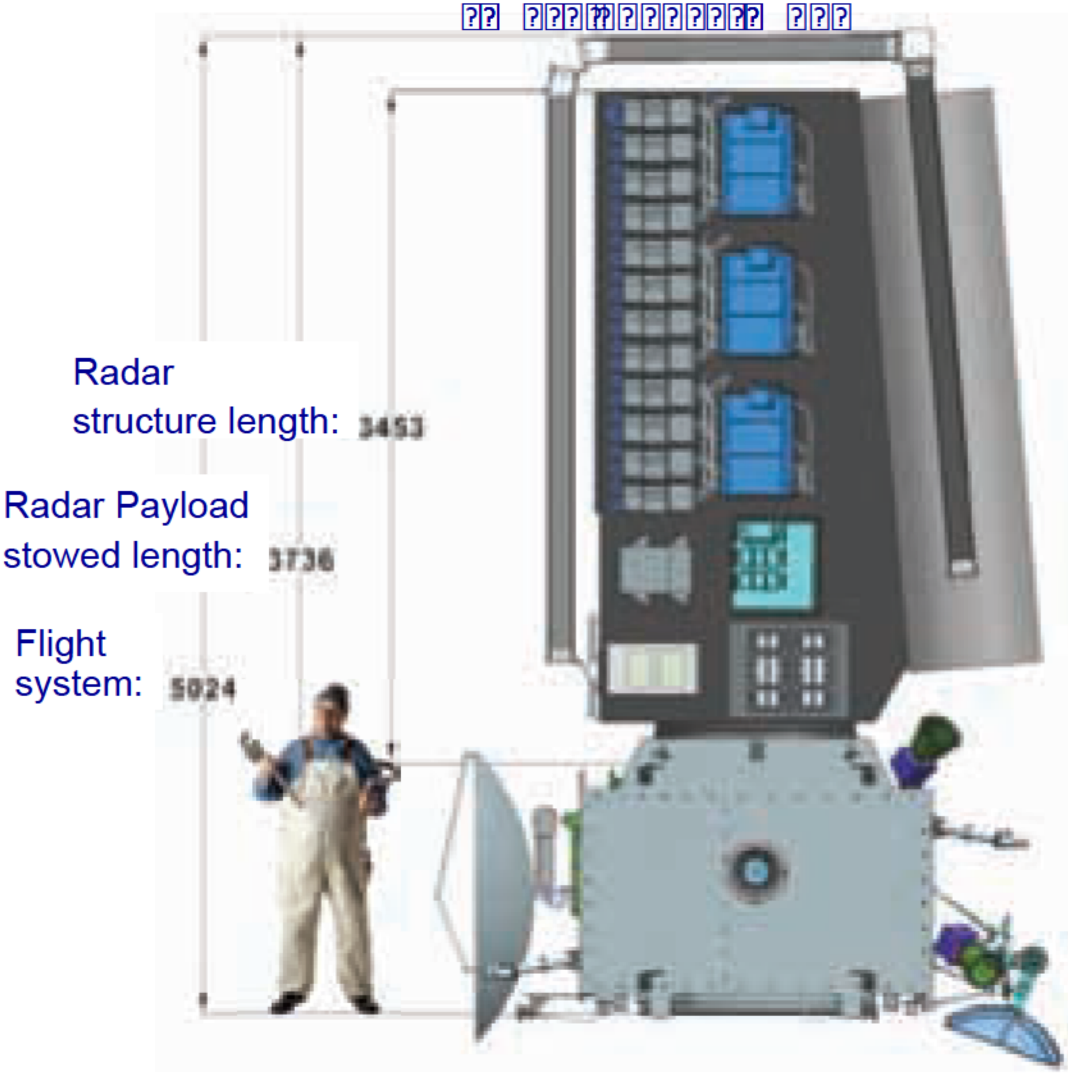
- World’s first dual frequency (L- and S- band) space-borne SweepSAR
- Repeat pass interferometry
- Fully polarimetric SAR capability
- Array-fed reflector (boresight at ~37 degrees from nadir, transmitting a fan beam, and receiving with multiple pencil beams)
  - Shared reflector for both L- and S-bands
  - Separate L- and S-band feeds
  - 240 km swath
- Observatory pointing control +/- 0.1°
- Active front-end electronics, high efficiency T/R module, high rate analog-to-digital converter (ADC), and on-board processing

SweepSAR algorithm was demonstrated using an airborne Ka-band SAR



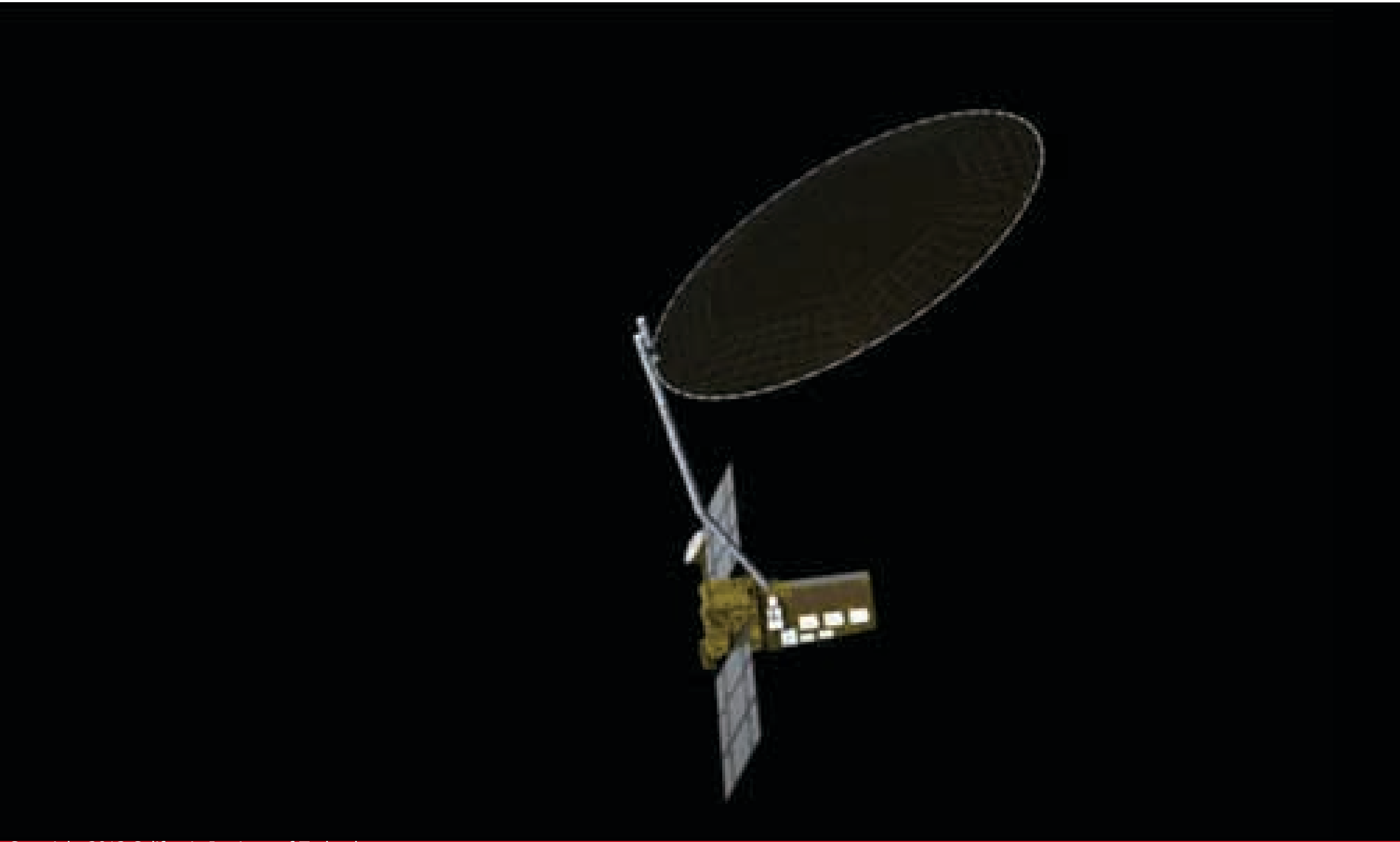
Sweep SAR Technique

Radar Payload & Flight System Configuration

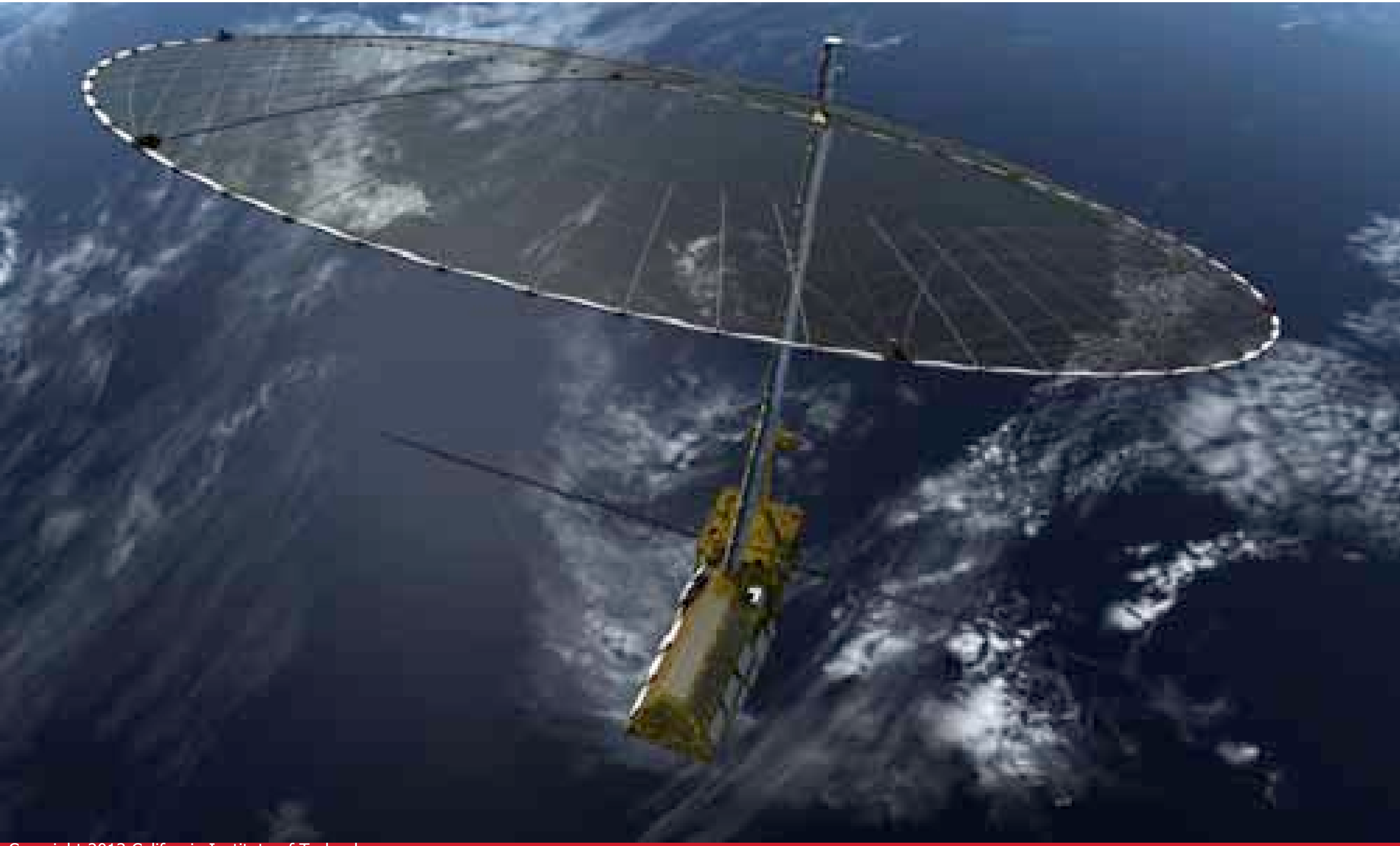


Flight System in Launch Configuration (India's GSLV)

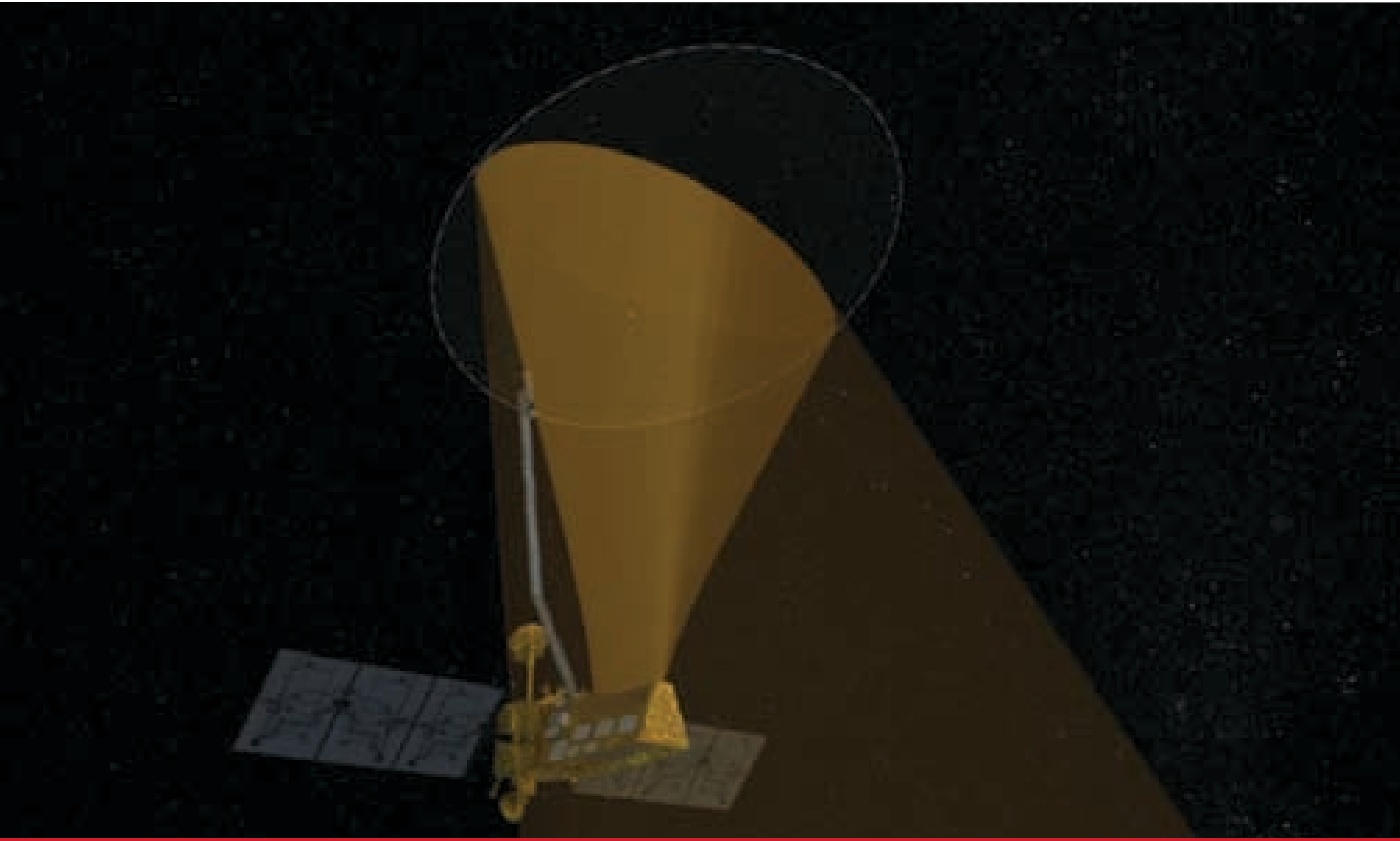
Radar Derived Damage Proxy Map vs Ground Truth



View from Reflector's Perspective

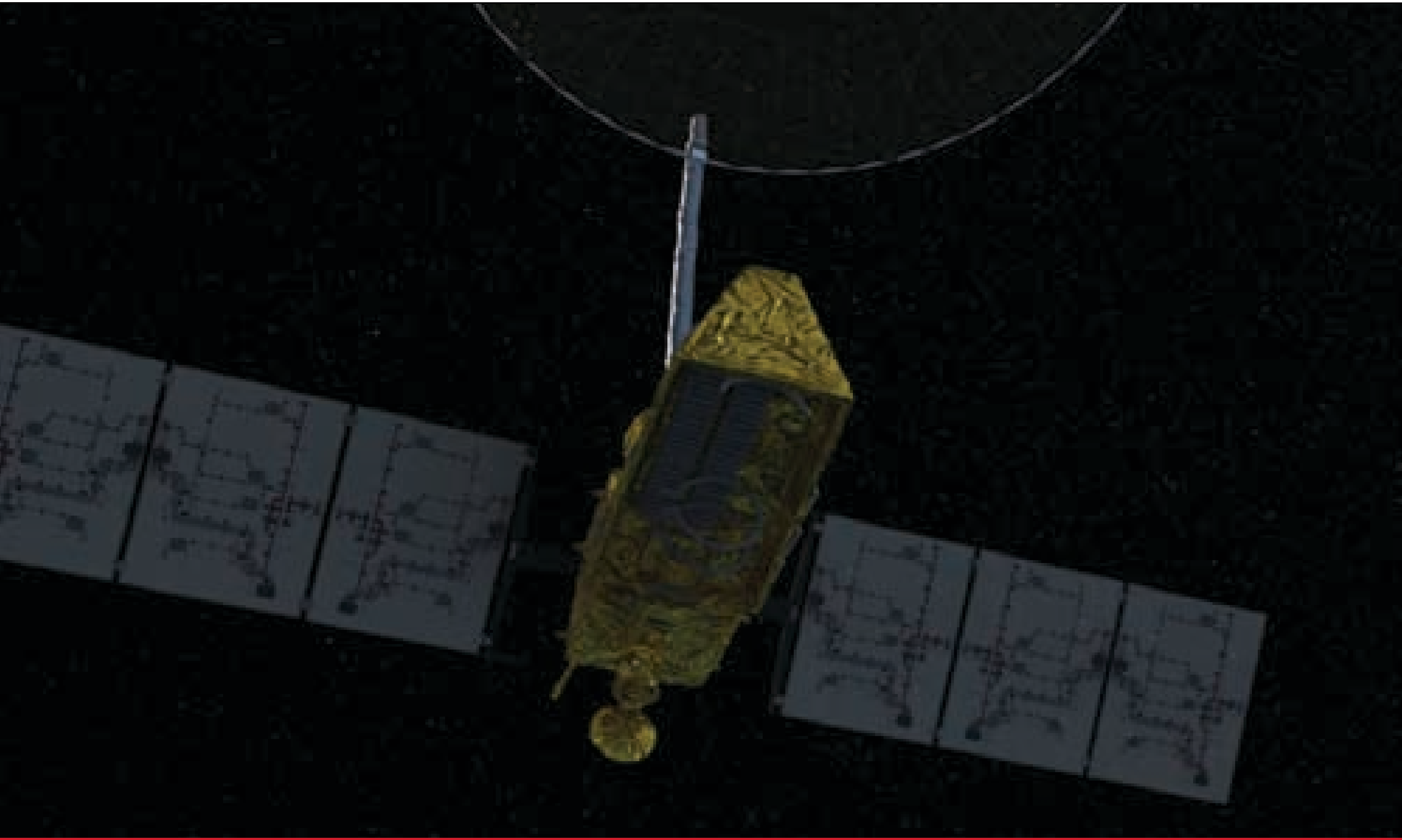


Illumination on the Reflector



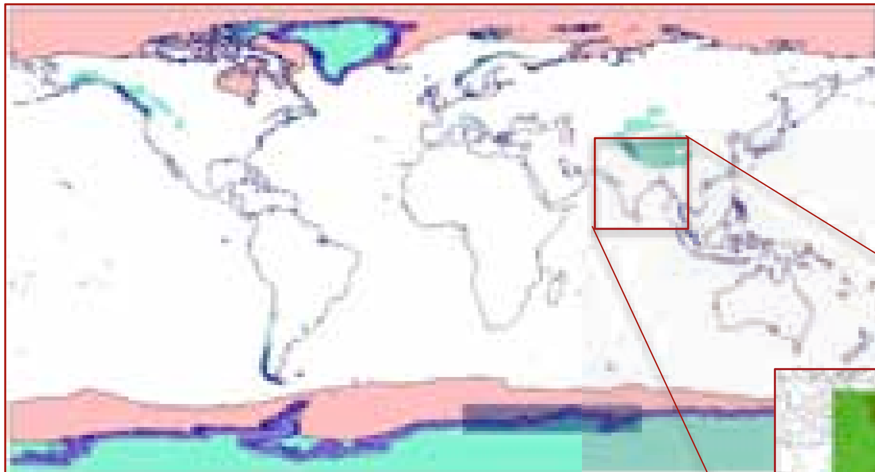
View of Two Telecom Systems

View of ISRO S-band Radar Hardware

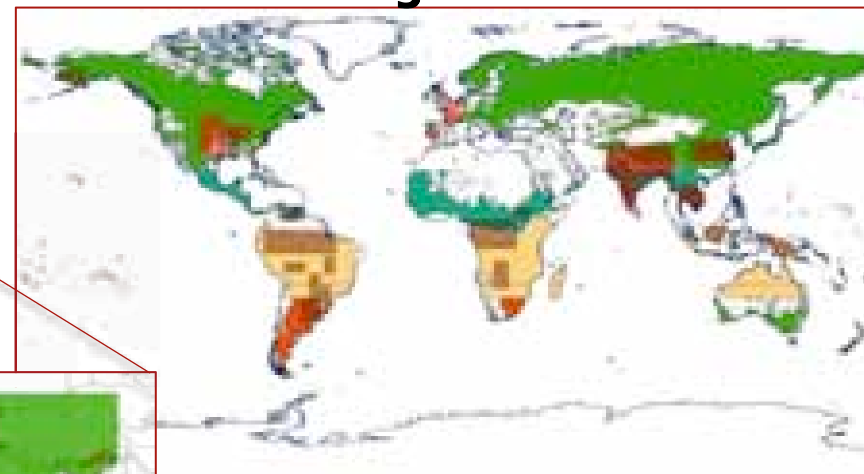


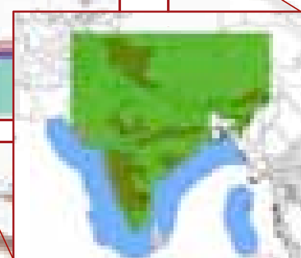
NASA-ISRO Comprehensive Observations Plan Exploiting L- and S-Band Radars

Global Ice Sheet and Glacier

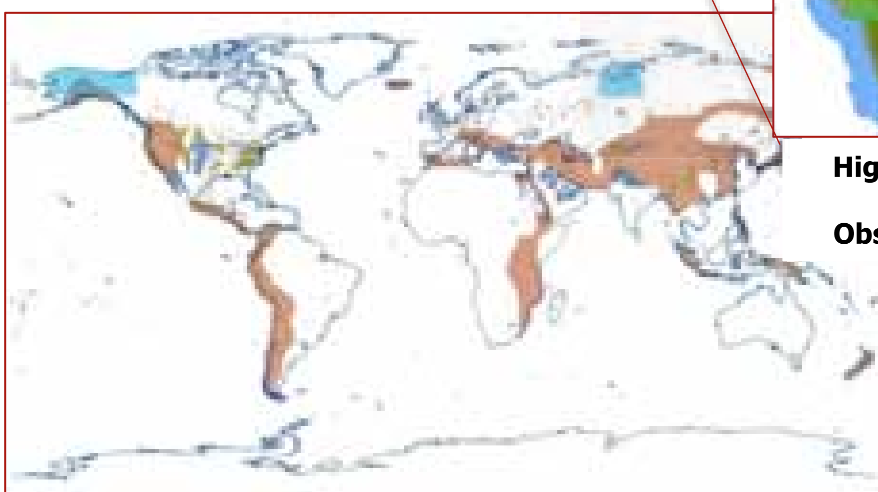


Global Vegetation Cover

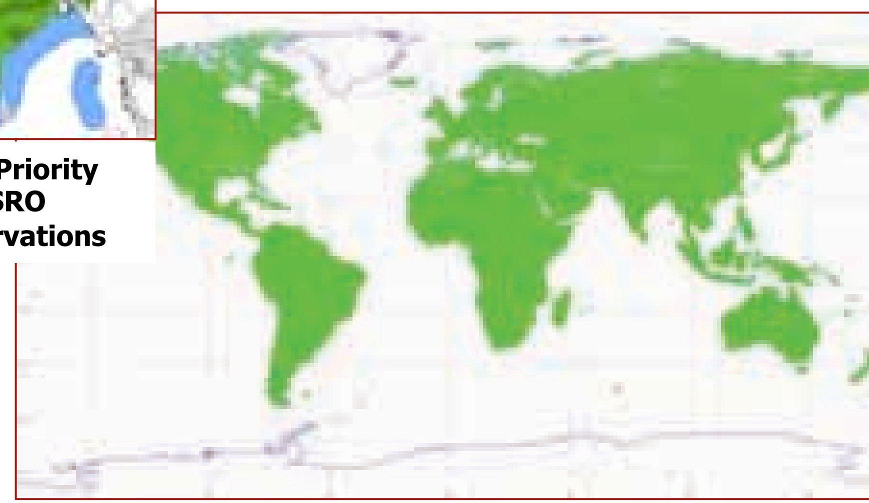




High Priority ISRO Observations



Global Deformation Science Areas



Global Background Mission

The NASA-ISRO SAR Mission Concept is Uniquely Designed to Address Societal Challenges

- A NASA-ISRO SAR Mission would realize the promise of the capabilities demonstrated in this presentation:
  - L-band SAR data
  - Additional S-band data to extend the range of sensitivity in critical areas
  - Reliable, regular, and frequent observations of areas of interest
  - Free, open access to data
  - Dense temporal and spatial sampling over the globe
- The NASA-ISRO SAR mission is the only mission concept designed to provide the needed measurements to realize this potential in the foreseeable future
- The mission would be a major source of data for many other agencies in the United States and India