# Radar Technology Development at NASA/JPL

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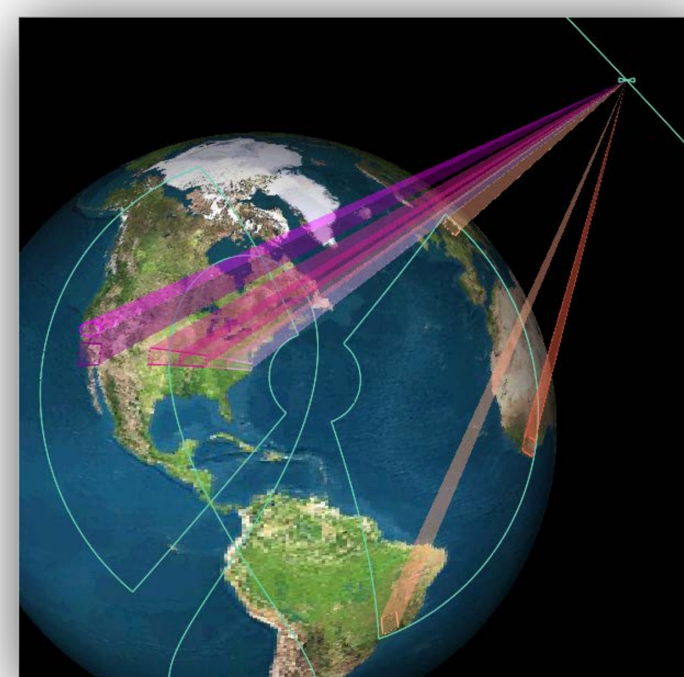
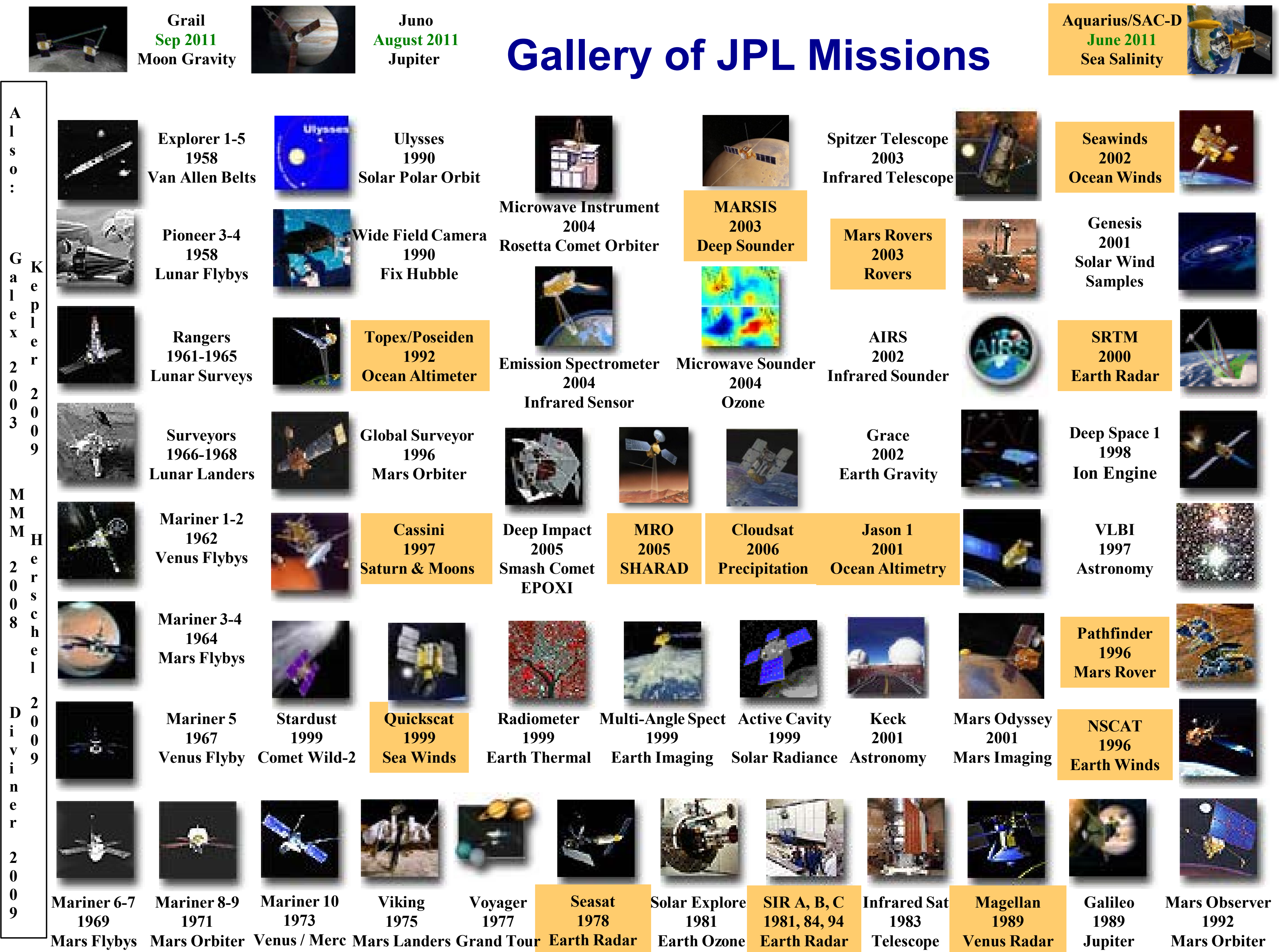


APSAR 2011
Seoul, Korea
September 26, 2011

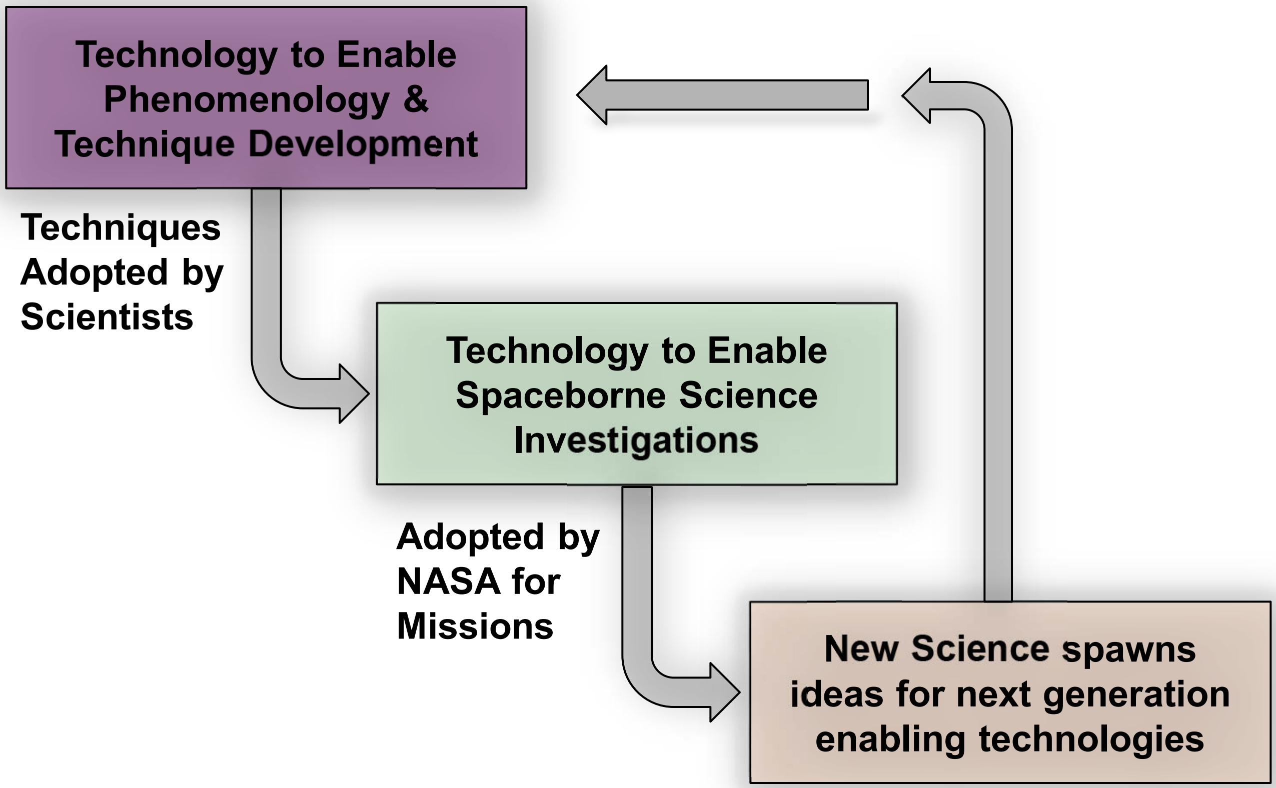
# What is Radar Technology?

- Technologies applied to JPL radar missions are typically defined at the *system* and *subsystem* level, for example:
  - Radar Interferometer
  - Membrane Phased-Array Antenna
  - Digital Beam-forming processor
  - Transmit/Receive Module
  - Characterizing stress points in electronics
- These technologies are synthesized from commercially available (flight qualified) components and devices
  - amplifiers, oscillators, circulators, FPGAs, DSPs, multi-layer boards, etc.
- JPL-conceived components devices occasionally needed
  - researched and developed by universities or small business manufacturers under contract



Gallery of JPL Missions
Grail
Sep 2011
Moon Gravity
Juno
August 2011
Jupiter
Aquarius/SAC-D
June 2011
Sea Salinity
Also:
Galex 2003
Kepler 2009
MMM 2008
Herschel 2009
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 Explore
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

# The Role and Flow of Technology Development




**Science-driven technology, focusing on**

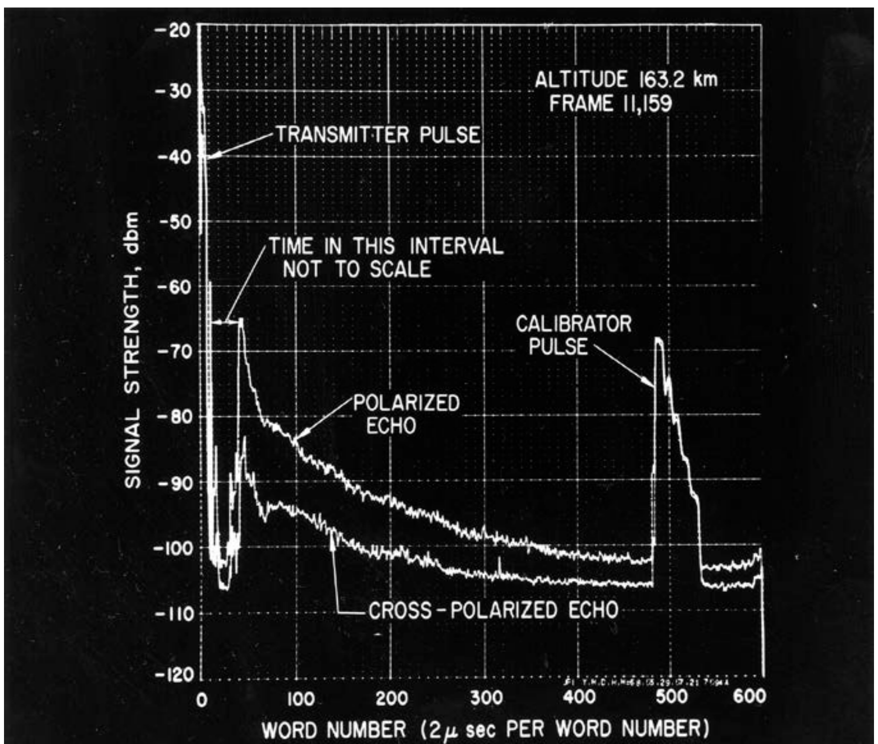
- Global reach and wide-area coverage
- High-performance, first-of-a-kind science

# NASA's Technology Programs

- Earth Science Technology Office
  - Advanced Component Technology
  - Instrument Incubator Program
  - Airborne Instrument Technology Transition
  - Advanced Information Systems Technology
- Planetary Science
  - Planetary Instrument Definition and Development Program
  - Mars Instrument Definition and Development Program
- Project-specific
  - Technology exploration in the preproject phase
  - Technology risk-reduction in the formulation phase

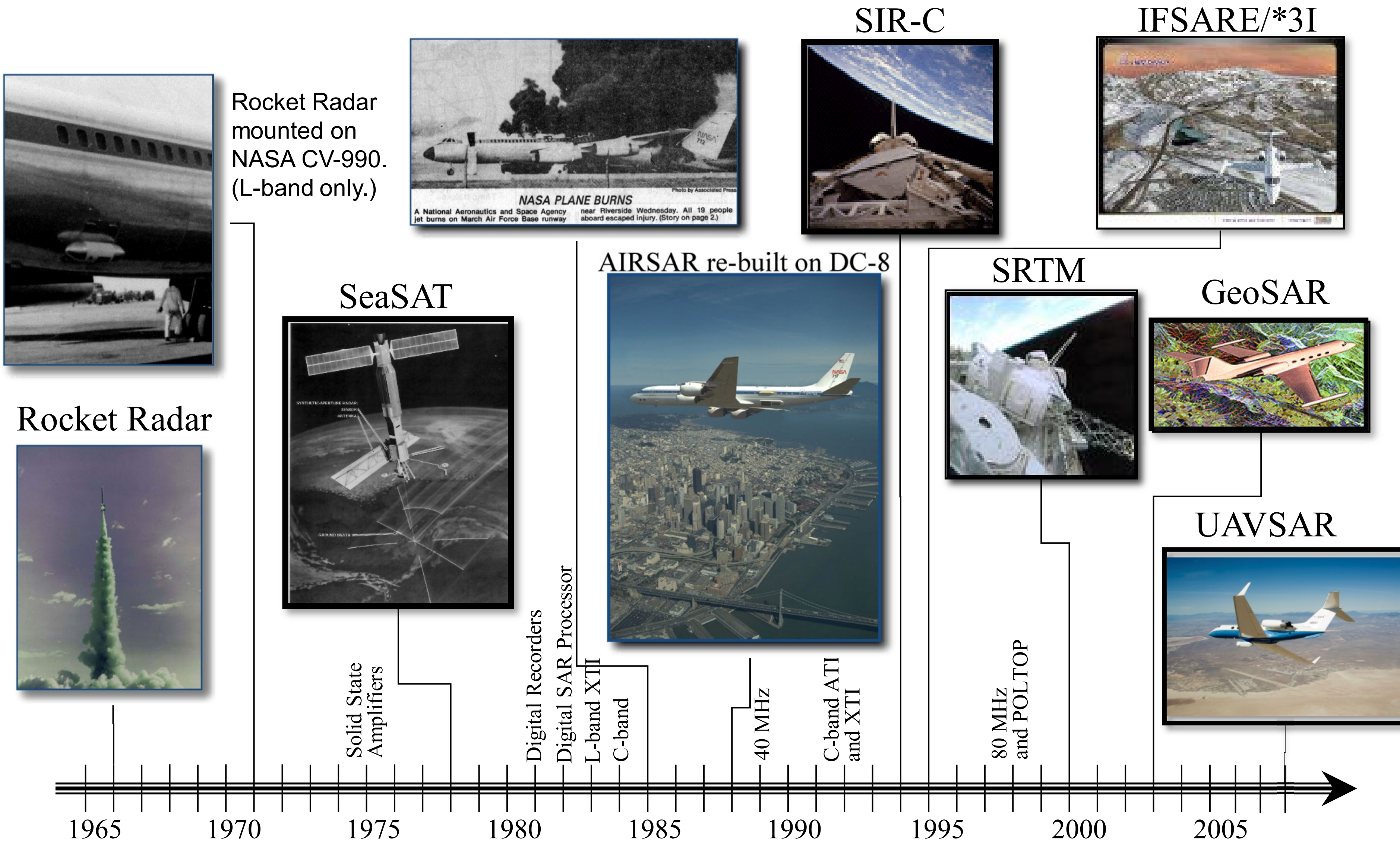
# Early JPL Radar Developments


1966 Rocket L-band Radar




1970- LHH Airborne Radar Image of Death Valley

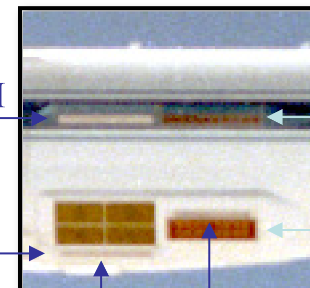
# The Flow of Technology in Airborne and Spaceborne SAR Programs



# The AIRSAR Instrument (1987-2004)

| Radar | C band | L band | P band |
|---|---|---|---|
| Frequency | 5.3 GHz | 1.3 GHz | 440 MHz |
| Power | 700 W | 4 kW | 2 kW |
| Noise-Equiv. sigma0 | -35 dB | -45 dB | -48 dB |
| Polarimetry | Quad | Quad | Quad |
| Interferometry | XTI, ATI | XTI, ATI | ------- |
| Height Accuracy | 1m / 5m | 2m / 10m | ------- |
| Velocity Accuracy | 10 cm/s | 4 cm/s | ------- |

| Bandwidth | 20 MHz | 40 MHz | 80 MHz |
|---|---|---|---|
| Radar | C/L/P | C/L/P | L |
| Data Posting | 10 meters | 5 meters | 3 meters |
| Number of Looks | 18 | 9 | 5 |
| Swath | 20 km | 10 km | 6 km |


**NASA Science:**

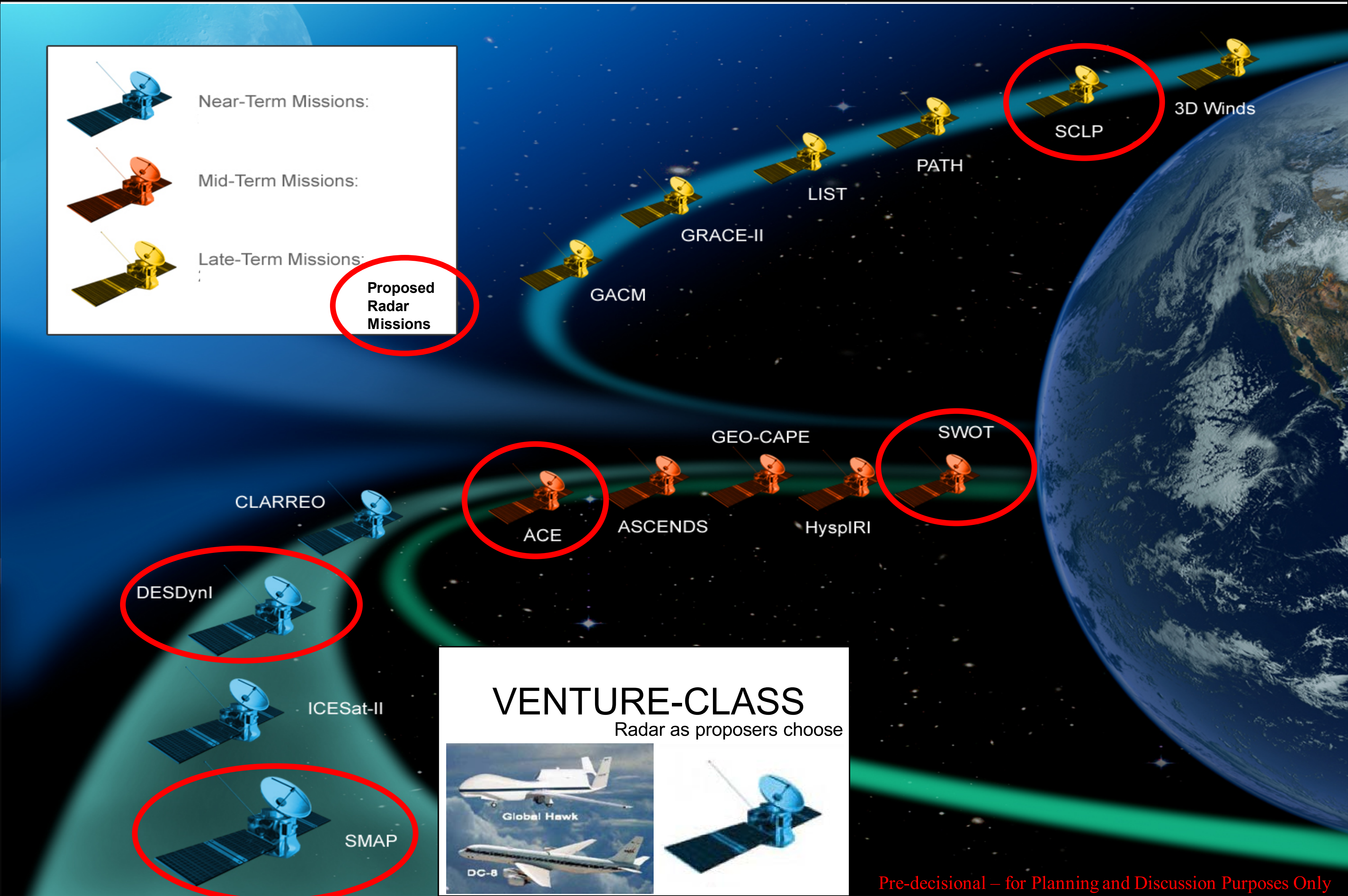
- Solid Earth
- Ecology
- Hydrology
- Land Cover
- Physical Oceanography
- Cryosphere
- Applications Program
- Space Science

**Typical applications:**

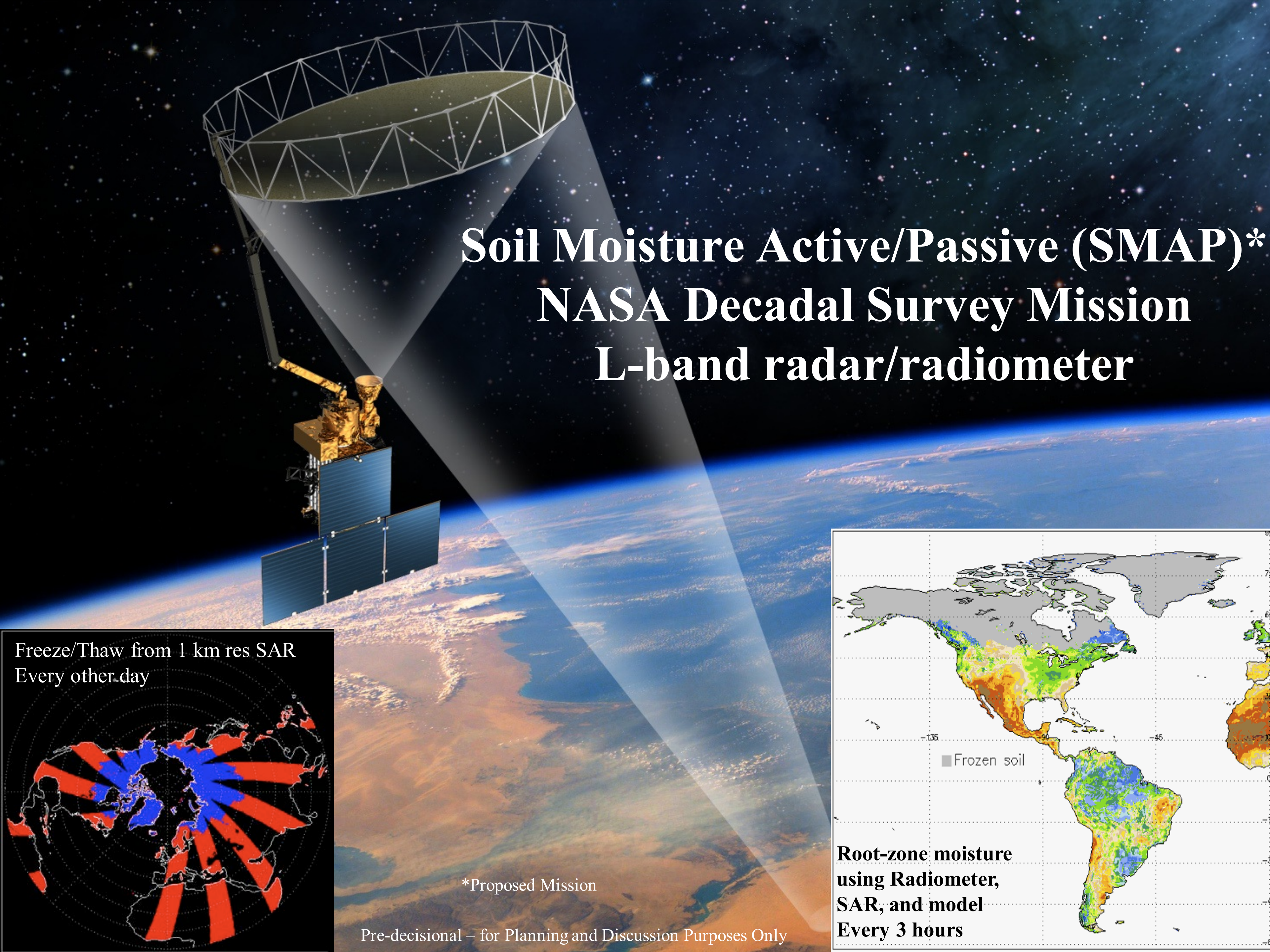
- Forestry Classification / Biomass Estimation
- Hazards:  oil spills, floods, UXO
- Agricultural Monitoring
- Urban Mapping/Telecom Studies
- Geological Mapping
- Oil and Gas Exploration
- Archaeology
- Coastal Currents, River Rates, Hydrology

*AIRSAR was a multi-frequency, quad-polarization, multi-baseline (three C-band and three L-band antennas) interferometric radar (TOPSAR).*

# NRC Earth Science Decadal Survey Missions

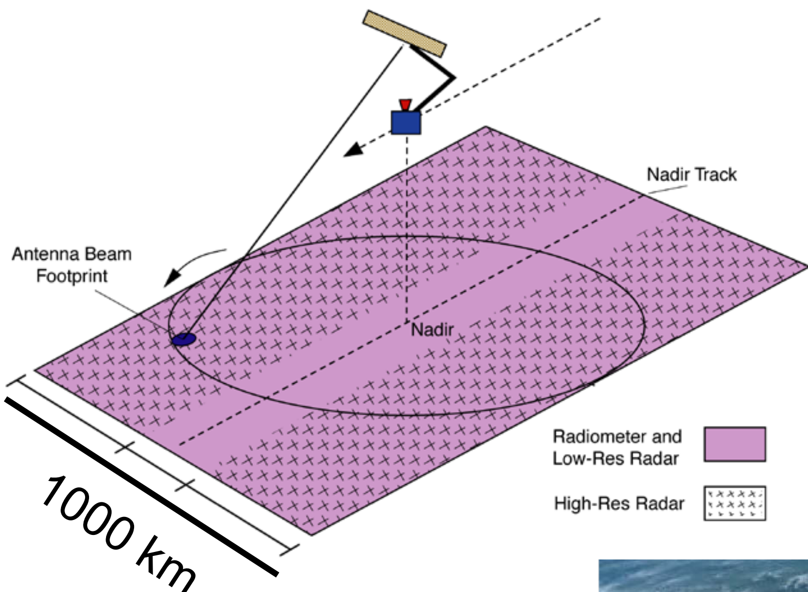


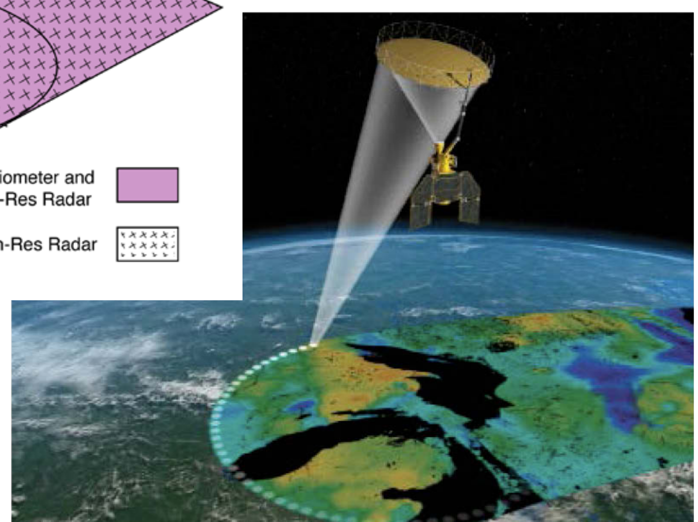

Pre-decisional – for Planning and Discussion Purposes Only


Soil Moisture Active/Passive (SMAP)*
NASA Decadal Survey Mission
L-band radar/radiometer
Freeze/Thaw from 1 km res SAR
Every other day
Frozen soil
-135
-45
Root-zone moisture
using Radiometer,
SAR, and model
Every 3 hours
*Proposed Mission
Pre-decisional – for Planning and Discussion Purposes Only

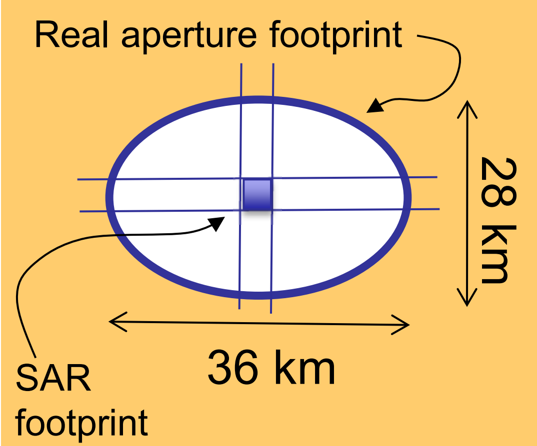
# Proposed SMAP Technology Solution for Required Soil Moisture Measurement

- To meet requirement for 3-day revisit time at AM local time:
  - ⇒ *1000 km swath at 685 km dawn/dusk sun-synchronous orbit.*
- For wide measurement swath of combined L-Band active and passive measurement at near constant incidence angle:
  - ⇒ *Conically scanning reflector antenna.*

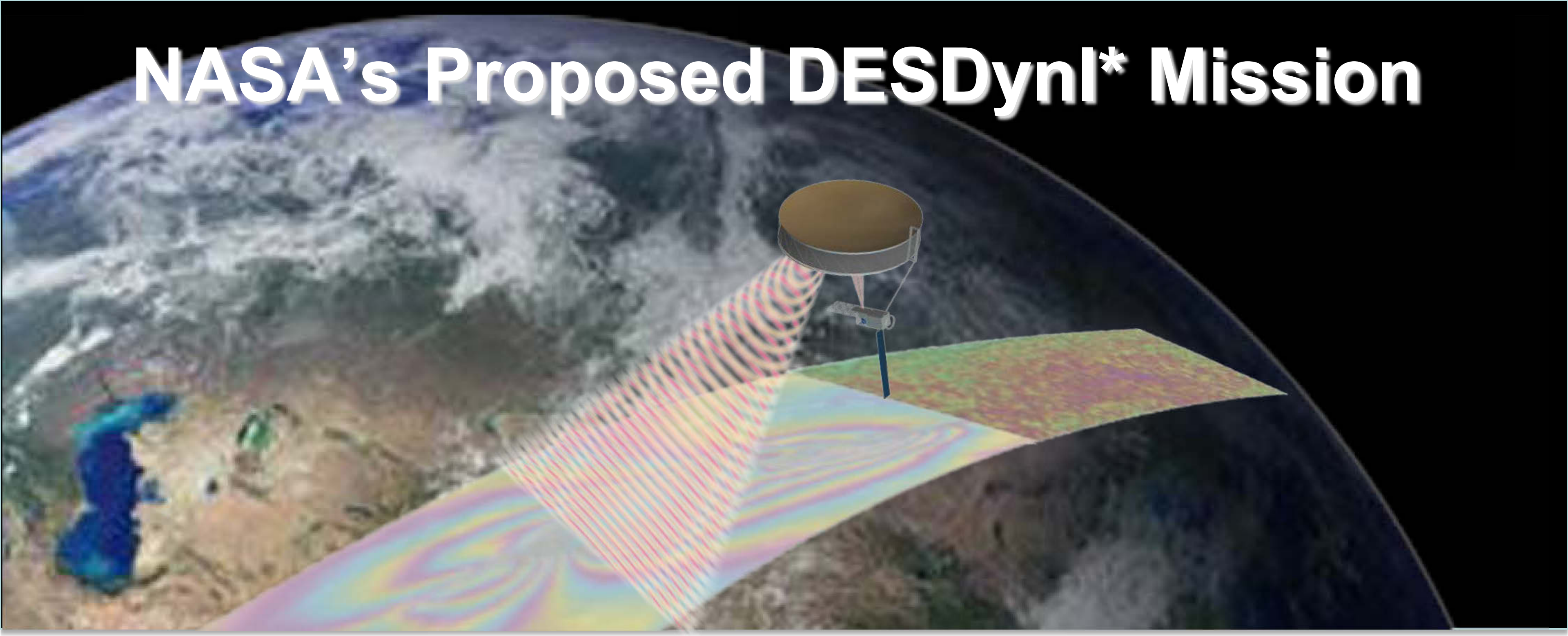


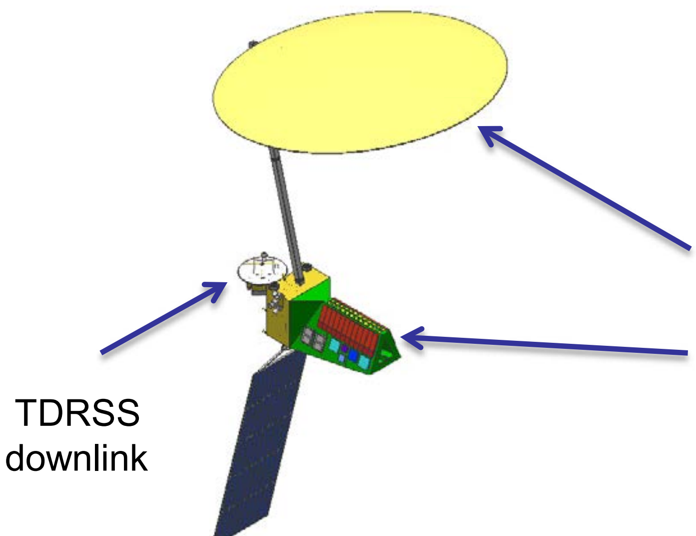



- Resolution required:
  - ✧ Radiometer: 40 km
  - ✧ Radar: 3 km
- ⇒ *6 meter aperture antenna*
- ⇒ *13 rpm rotation rate*
- ⇒ *Real-aperture radiometer*
- ⇒ *Synthetic-aperture radar processing* exploiting "mechanical TOPS mode"



# NASA's Proposed DESDynI* Mission






Radar designs for proposed DESDynI mission being studied in pre-Phase A

L-band 5-80 MHz BW Quad-pol Radar
9-15 m mesh reflector
12-24 element transmit and receive array
12-24 dual-pol receive channels
180-360 km swath, full res, full-pol
Better than -25 dB NES0 at 20 MHz BW

*DESDynI - Deformation, Ecosystem Structure, and Dynamics of Ice

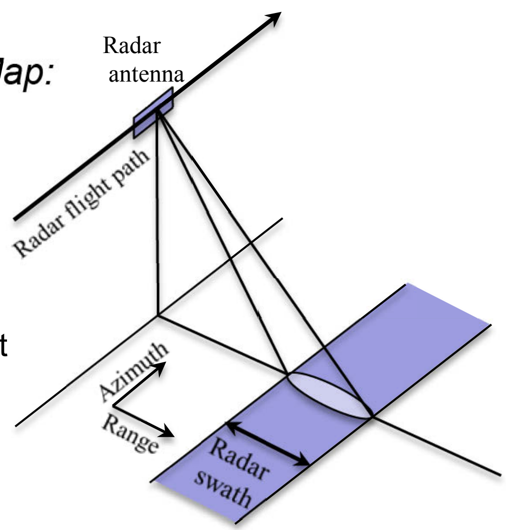
# Radar Design to Meet Critical Requirements

- Repeat Period requirement for Deformation science drives the Radar Swath
  - 8M-day Repeat Period => 360/M-km Swath Width
- Sensitivity requirement for Biomass (cross-pol) measurement drives Antenna Size and Radar Power
- Accuracy requirements for Deformation and Biomass drive Electronics & Mechanical Stability and Calibration

- A new SweepSAR technique was adopted as a means to achieve much wider swath than conventional SAR strip-mapping, without the performance sacrifices associated with the traditional ScanSAR technique

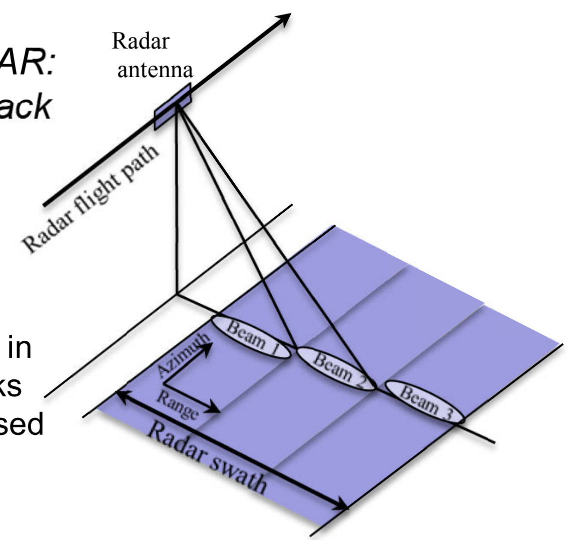
*Conventional StripMap: <~70km Swath*

Resulting ~40 day repeat does *NOT* meet proposed Deformation and Ice Science Requirements



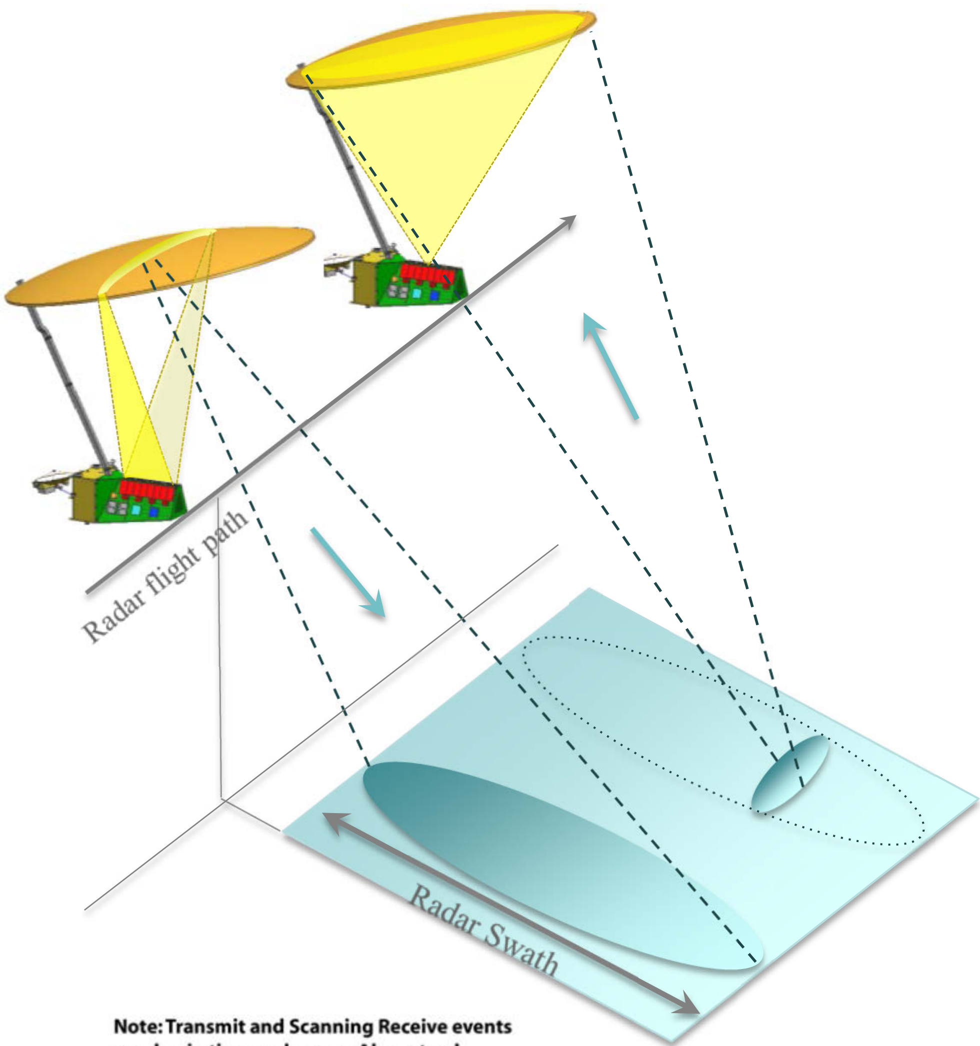

*Conventional ScanSAR: non-uniform along-track sampling*

Resulting degradation in effective azimuth looks does *NOT* meet proposed Ecosystem Science Requirements



# SweepSAR Technique

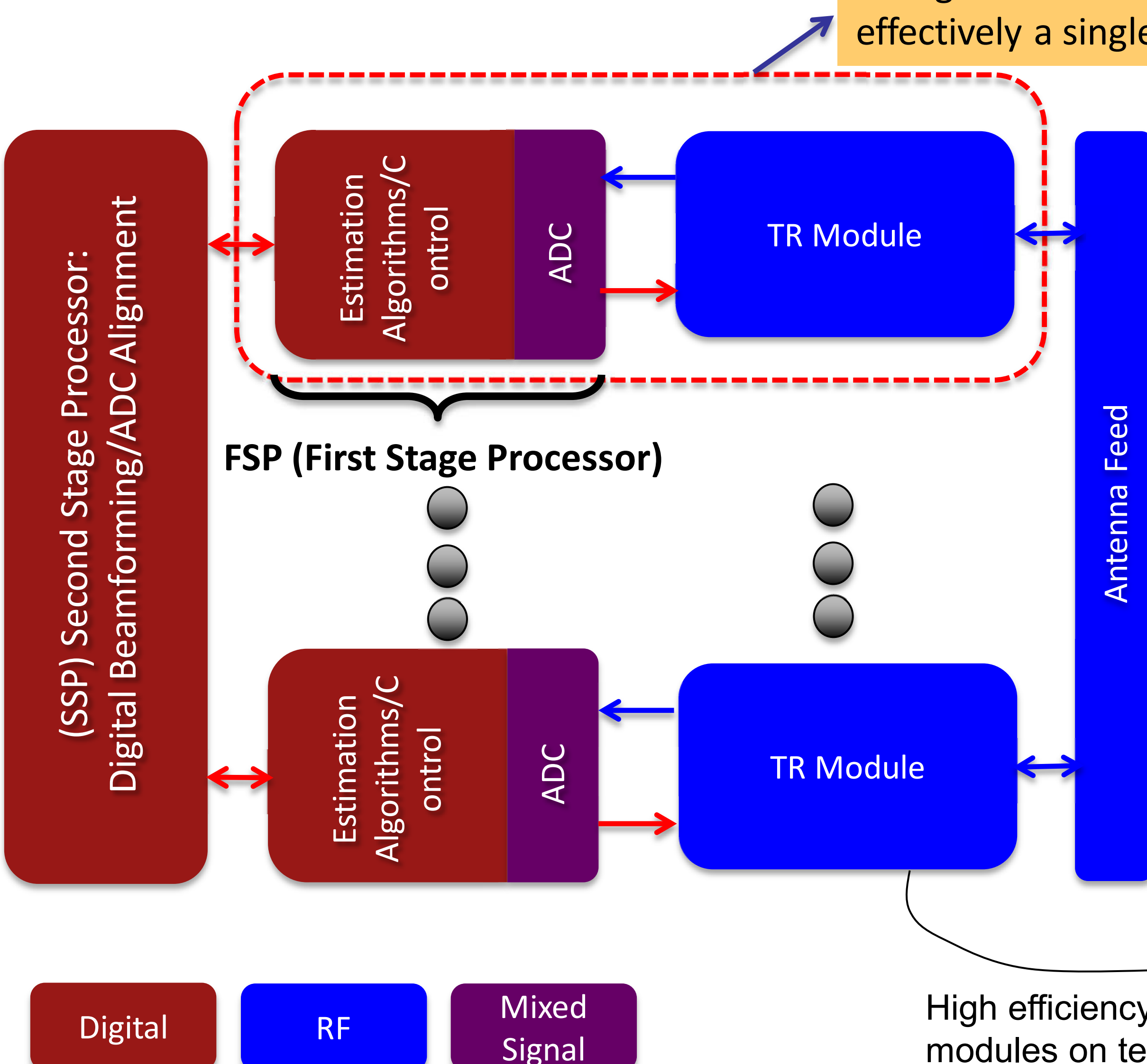
- On Transmit, all Feed Array elements are illuminated (*maximum Transmit Power*), creating the wide elevation beam
- On Receive, the Feed Array element echo signals are processed individually, taking advantage of the full Reflector area (*maximum Antenna Gain*)
- Uses *digital beamforming* to provide wide measurement swath
  - DBF allows multiple simultaneous echoes in the swath to be resolved by angle of arrival
- Uses large reflector to provide high aperture gain
  - Full-size azimuth aperture for both transmit and receive
  - Full-sized elevation aperture on receive
- Only need data from feed array elements being illuminated by an echoes
  - These elements can be predicted *a priori*




Note: Transmit and Scanning Receive events overlap in time and space. Along-track offset shown is for clarity of presentation only.

# High-level Block Diagram of Beamformer/Calibration and TR Front End Technologies

A single channel RF/Digital channel, effectively a single functional block



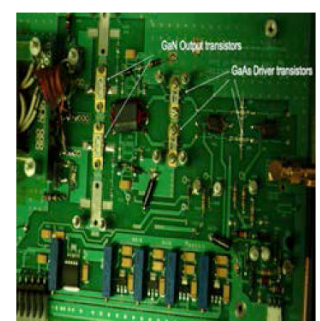

**The First Stage Processor for the proposed DESDynI SAR Instrument…**

**on Transmit:** Receives a coupled replica of the transmitted RF Chirp

**on Receive:** Receives a Caltone simultaneously with the radar return.

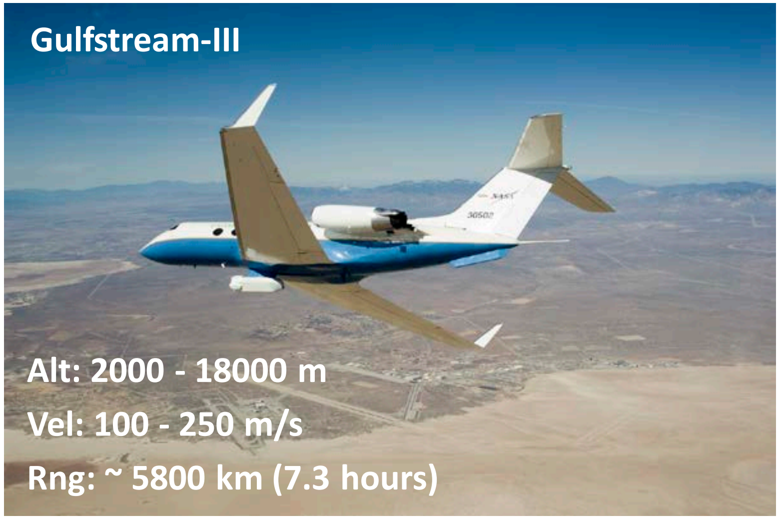
**on Bypass Calibration**: Receives an RF Chirp or Caltone is directly in the FSP

Signals are used to estimate and correct amplitude and phase fluctuations




High efficiency GaN TR modules on test fixture

# UAVSAR Airborne Radar




- UAVSAR is an L-band fully polarimetric SAR designed to support a wide variety of science

Key technologies:

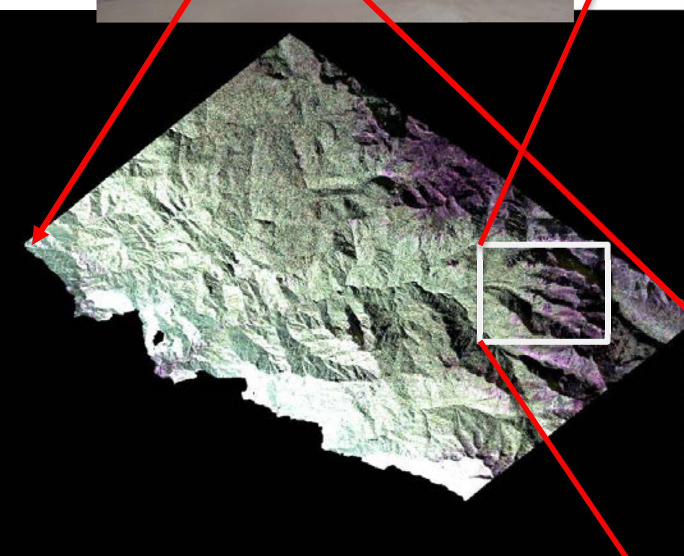
- ✧ A *precision autopilot* developed by NASA Dryden that allows the platform *to fly repeat trajectories that are mostly within a 5 m tube*.
- ✧ Compensates for attitude angle changes during and between repeat tracks by *electronically pointing the antenna* based on attitude angle changes measured by the INU.

| Parameter | Value |
|---|---|
| Frequency | L-Band 1217.5 to 1297.5 MHz |
| Bandwidth | 80 MHz |
| Resolution | 1.67 m Range, 0.8 m Azimuth |
| Polarization | Full Quad-Polarization |
| ADC Bits | 2,4,6,8,10 & 12 bit selectable BFPQ, 180Mhz |
| Waveform | Nominal Chirp/Arbitrary Waveform |
| Antenna Aperture | 0.5 m range/1.5 azimuth (electrical) |
| Azimuth Steering | Greater than ±20° (±45° goal) |
| Transmit Power | > 3.1 kW |
| Polarization Isolation | <-25 dB (<-30 dB goal) |
| Swath Width | > 23 km |

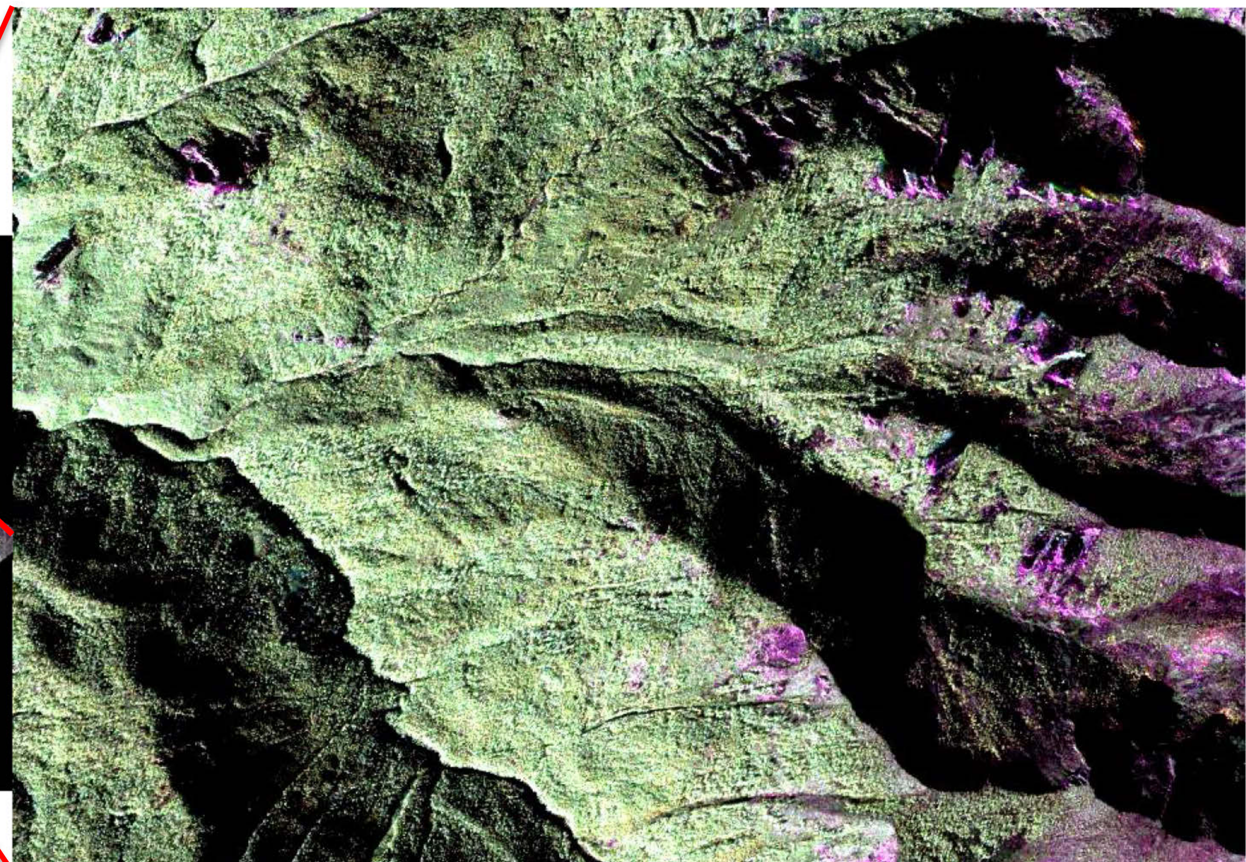
**Project Scientist: Scott Hensley**
**Project Manager: Yunling Lou**

# Mapping Kings Canyon Forest Fire Fuel Load with UAVSAR Data

**Supports DESDynI Biomass Estimation and Radar/Lidar Fusion Algorithm Development**

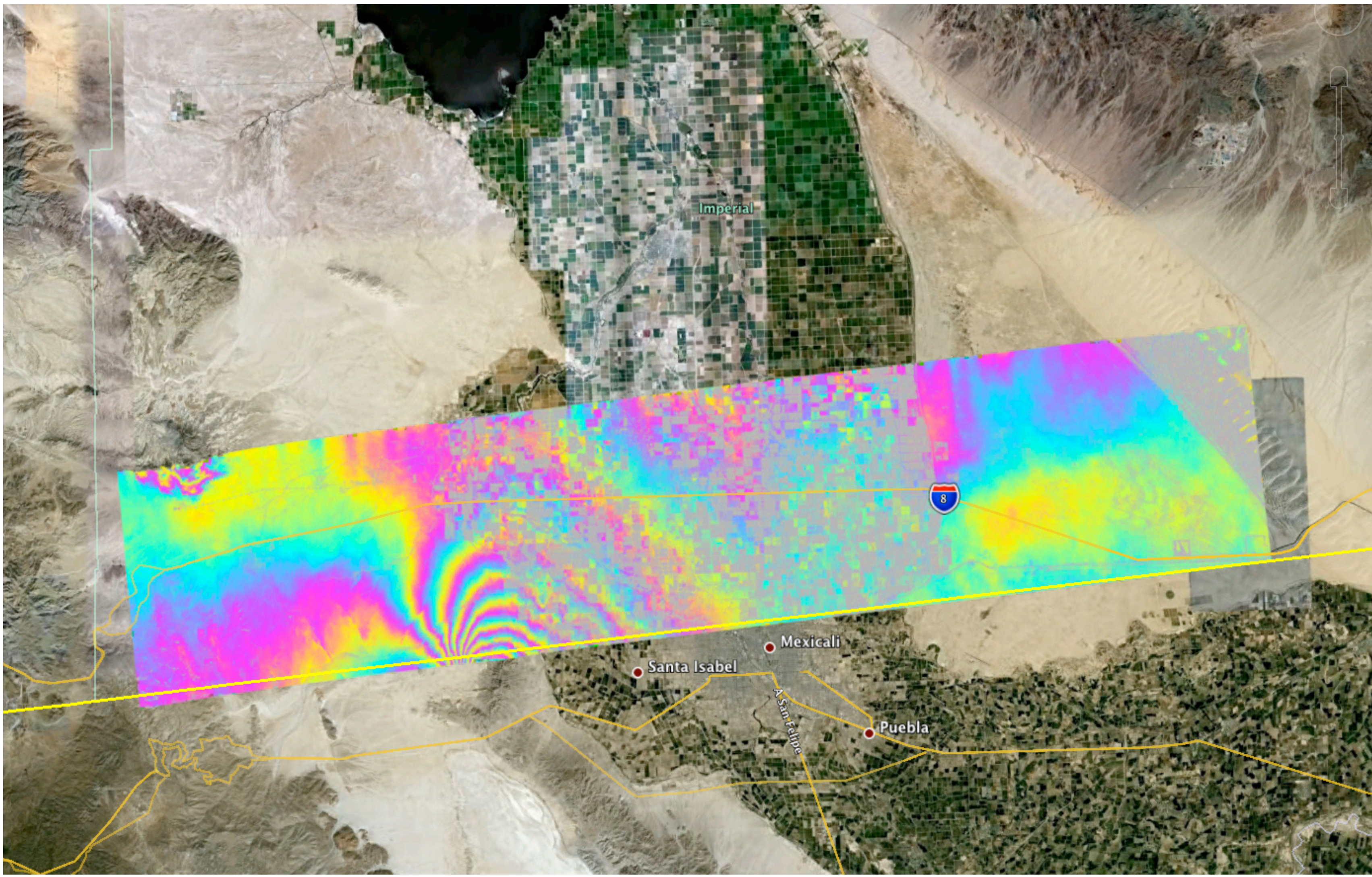


LHH, LHV, LVV



# April 4, 2010 M 7.2 Baja California Earthquake

First earthquake deformation captured by the UAVSAR system using data acquired on October 21, 2009 and April 13, 2010



SWOT

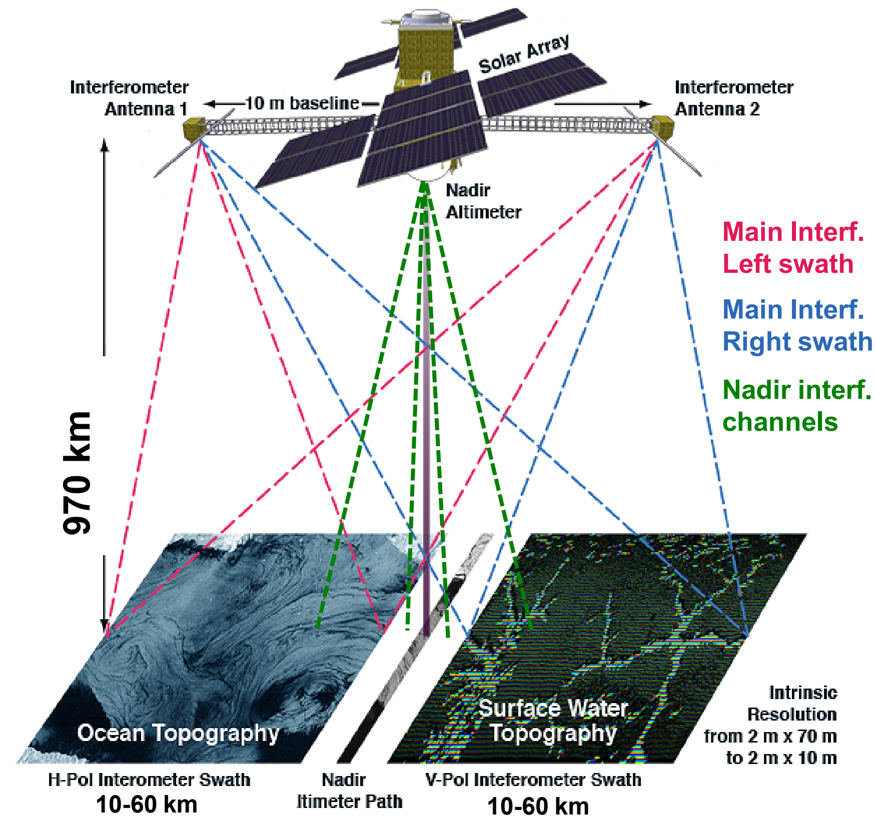
# SWOT* Overview

## Proposed Mission Science

**Oceanography:** Characterize the ocean mesoscale and sub-mesoscale circulation at spatial resolutions of 10 km and greater.

**Hydrology:** To provide a global inventory of all terrestrial water bodies whose surface area exceeds (250m)$^2$ (lakes, reservoirs, wetlands) and rivers whose width exceeds 100 m (requirement) (50 m goal) (rivers).

- To measure the global storage change in fresh water bodies at sub-monthly, seasonal, and annual time scales.
- To estimate the global change in river discharge at sub-monthly, seasonal, and annual time scales.




## Mission Architecture

- Ka-band SAR interferometric (KaRIn) system with two swaths, 50 km each (goal of 60 km)
- Would produce heights and co-registered all-weather imagery
- Use conventional Jason-class altimeter for nadir coverage, radiometer for wet-tropospheric delay, and GPS/Doris/LRA for POD.
- On-board data compression over the ocean (1 km$^2$ resolution). No land data compression onboard.

- Partnered mission with CNES
- Mission life of 3 years
- 970 km Orbit, 78º Inclination, 22 day repeat
- Flight System: ~1400Kg, ~2.1kW
- Readiness for launch 2019 (TBC)





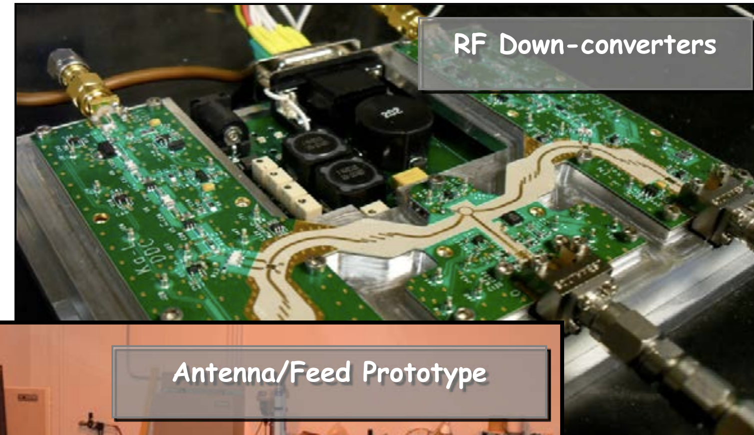


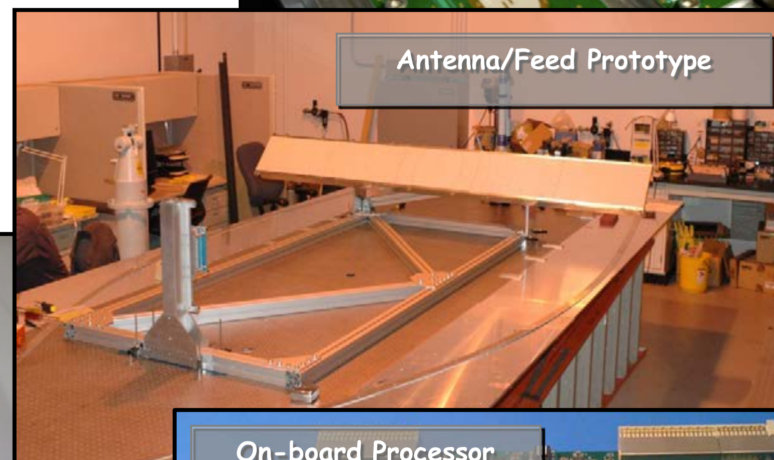
*Proposed Mission

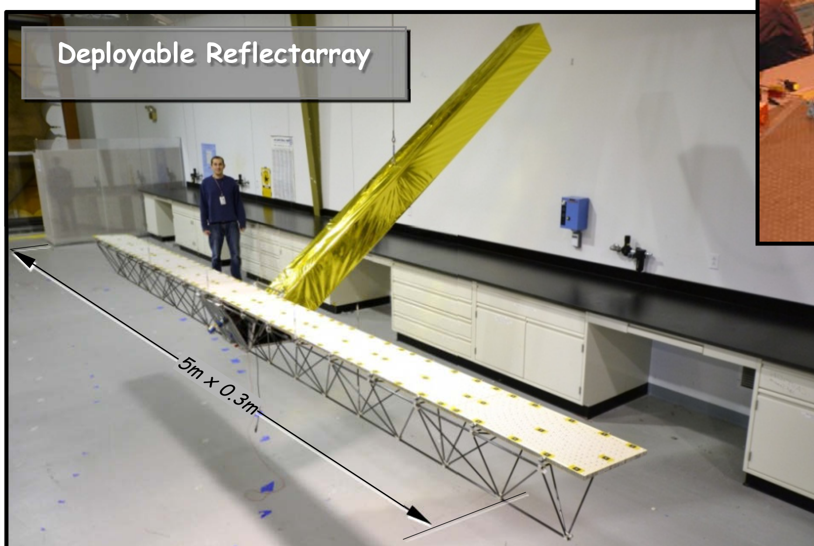
SWOT

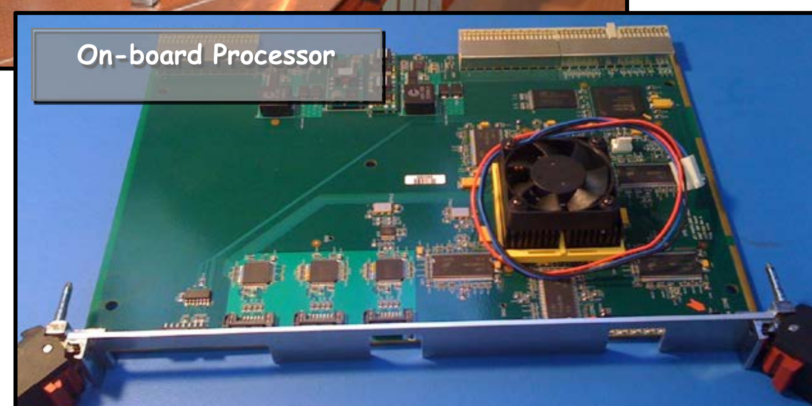
# SWOT* Technology Drivers

- The proposed SWOT mission would drive the technology for:
  - The stability of the mast, the reflectarray antenna and its deployable support structure
  - On-board interferometric SAR processing to meet downlink capabilities
  - Ka-band RF electronics:
    - Phase stable RF dual-downconverter
    - High power Amplifier (Extended Interaction Klystron and High-Voltage Power Supply)



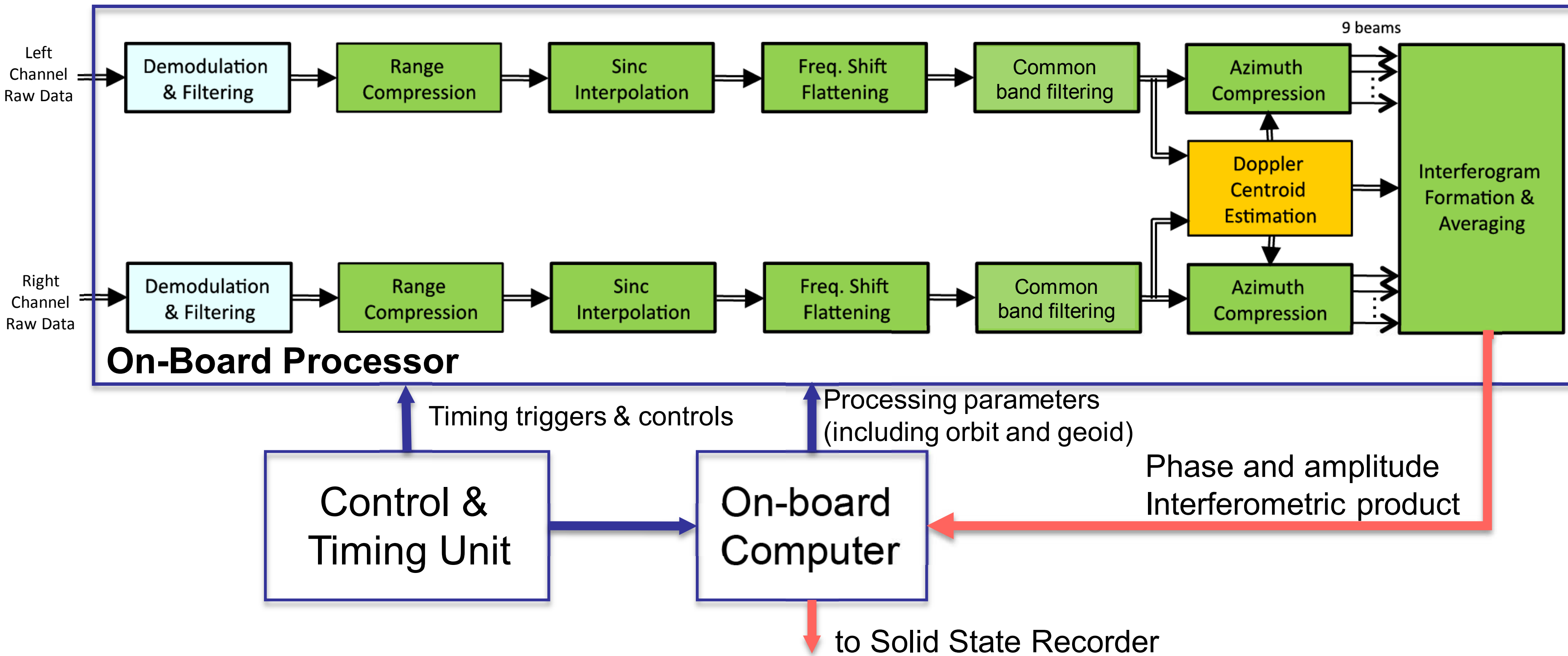



Pre-decisional – for Planning and Discussion Purposes Only

*Proposed Mission

**Operating parameters:**

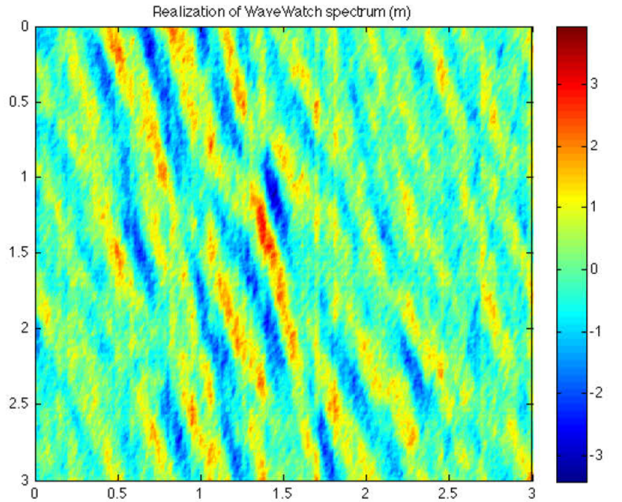
- 200 MHz signal bandwidth (0.75 m slant range resolution)
- ~ 5 KHz maximum PRF per channel
- 2 x 60 km cross-track swaths
- Single-look ground resolution: 10-70m in range, ~250m in azimuth
- Output resolution: 1x1 km (~200 kbps; a reduction factor of 1,450)
- Height error budget for OBP: 2 mm @ 1x1 km (∞ SNR)



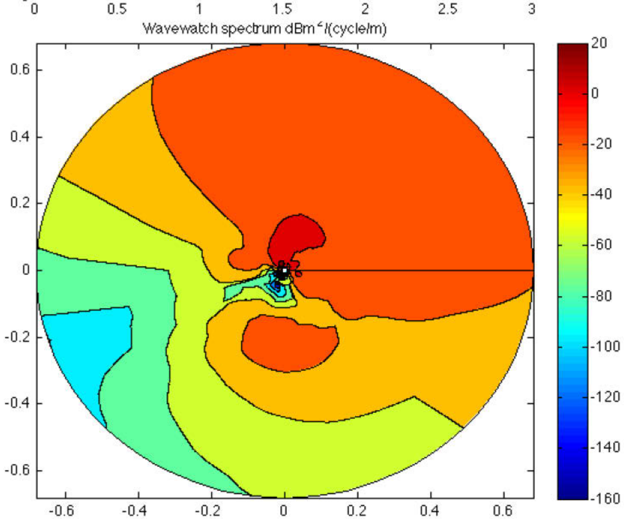
# SWOT On-board Processor Performance Example

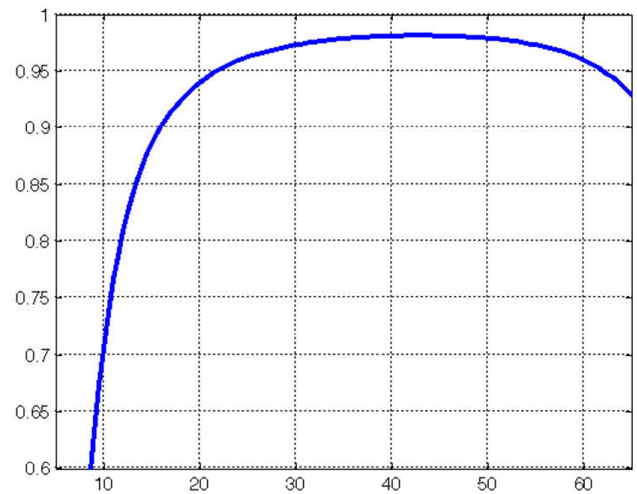
On-going effort to generate raw data with simulated WaveWatch III wave fields

WaveWatch III Realization (SWH=3m)

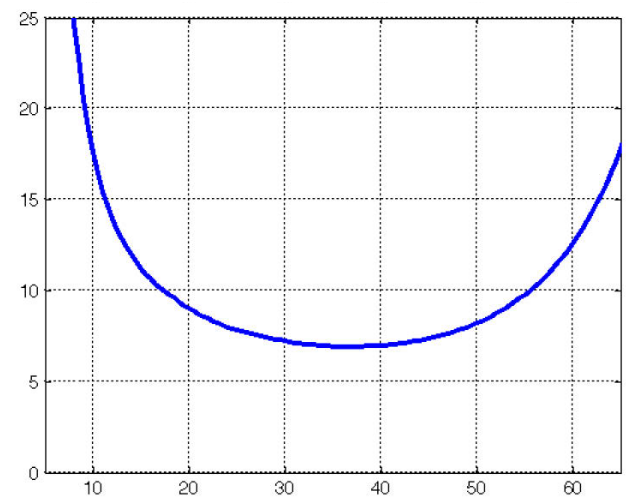



Corresponding wave spectrum




Coherence (including OBP+SNR)




random error performance (including OBP+SNR)

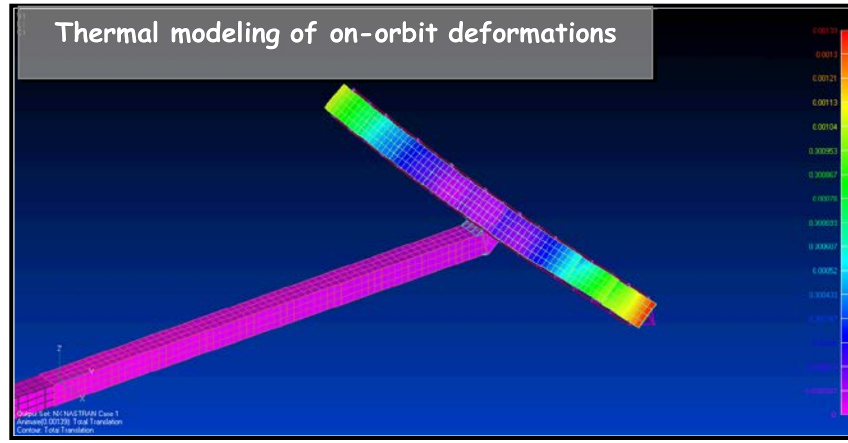
Mean error = 9 mm

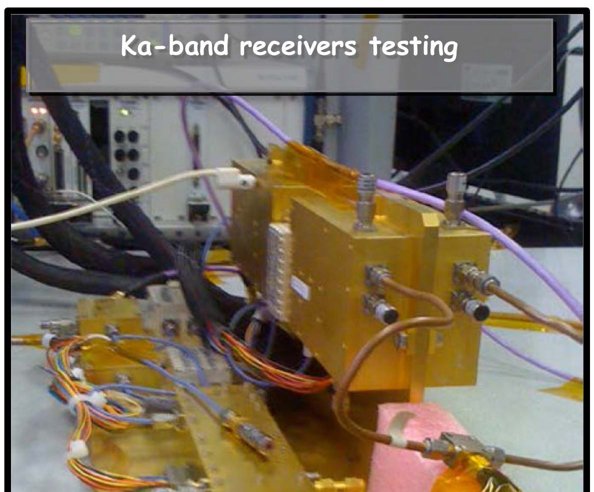
**OBP only mean error ~ 1.0 mm**

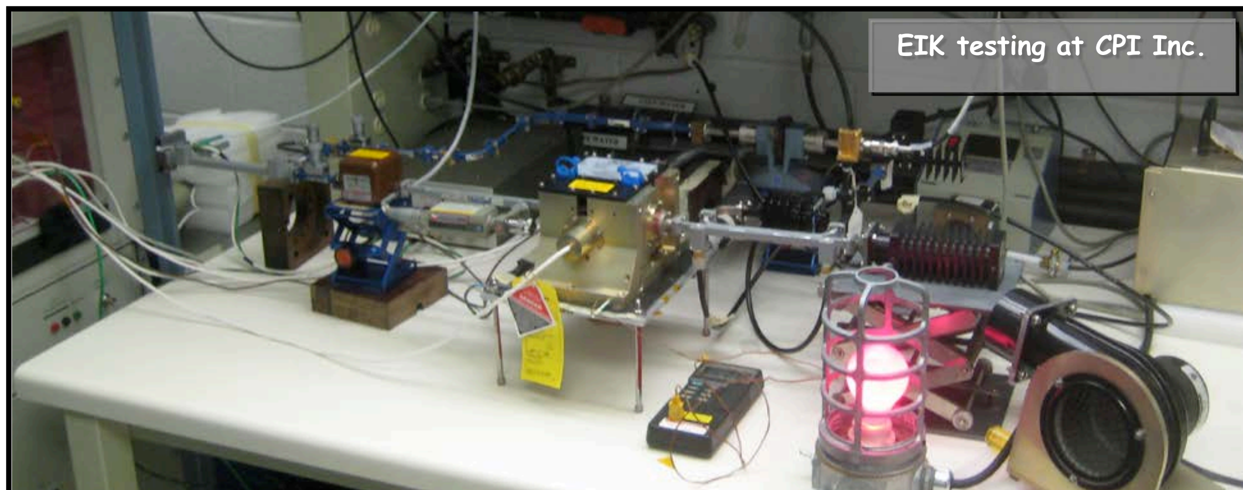
# Phase stability

The interferometer instrument needs to maintain the relative and absolute phase integrity across its elements, in particular:

- RF Ka-band receivers need to phase track to within a few tens of milli-degrees of phase over ~2.5 minutes.
- Antenna and mast distortions due to thermoelastic effects translating into phase errors need to be controlled by design
- The radar transmitter (and the High Power Amplifiers in particular) needs to meet stringent phase stability requirements



# Ka-band Interferometer for Ice Surface Topography


Ka-band antennas installed on the NASA GIII configured for single-pass interferometry

For the International Polar Year NASA funded a Ka-band single-pass interferometer utilizing UAVSAR for ice surface topography swath-mapping

- Will characterize the interferometric penetration depth of Ka-band into snow cover.
- Critical to the feasibility of a future radar ice surface topography mapping mission.

**First known demonstration of millimeter-wave single-pass interferometry**

*Relevant not only for Earth ice-surface topography, but also surface water, ocean surface topography and interplanetary (e.g. Europa) ice cover measurements*

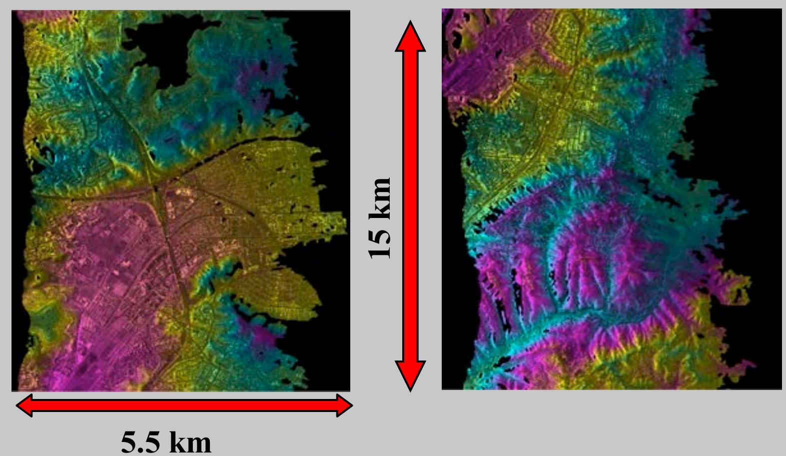



Image from the second engineering test flight on 3/16/09. Aircraft flew on a heading of 180° and imaged from San Dimas, CA down to Irvine at an altitude of 6km. The swath width is ~5.5 km and the data was processed to a height map with posting of 3 meters. The height precision varies from about 30 cm (near range) to 3 m in (far range).


**Investigators:** D. Moller (PI), S. Hensley, G. Sadowy, E. Rignot, M. Simard


REMOTE SENSING SOLUTIONS

# UAVSAR Instrument Pods – Modular Technology Testbeds for New Systems

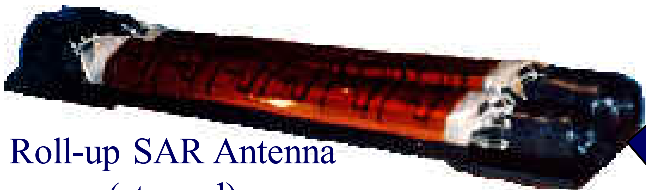
Operational L-band pod

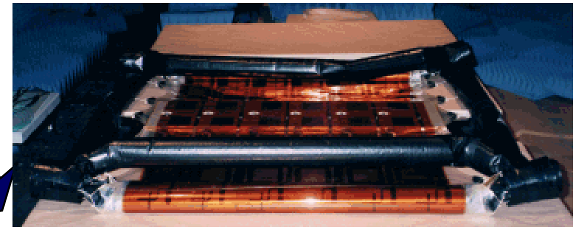
Pod in experimental Ka-band configuration (includes a new passive Ka-band antenna)

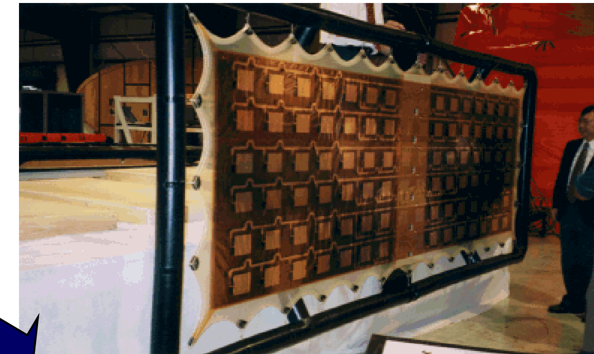
Also modified for P-band (AIRMOSS)

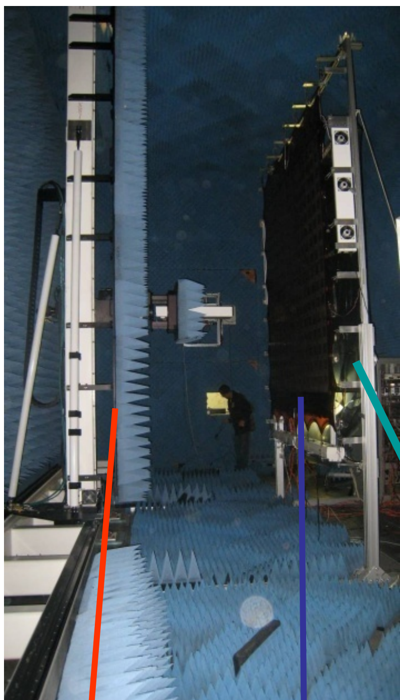
Planning to further miniaturize electronics to fly multiple pods and on smaller platforms

# Membrane Phased Array Technology for very large (>400 m$^2$) MEO/GEO antennas

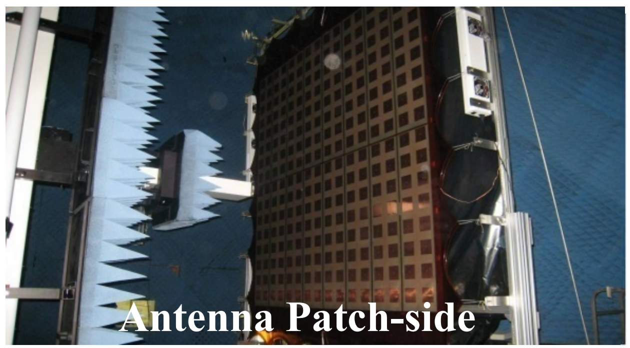

Roll-up SAR Antenna (stowed)

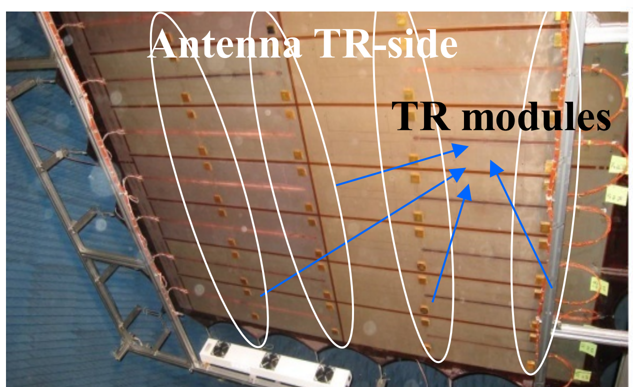

Roll-up SAR Antenna (partially deployed)

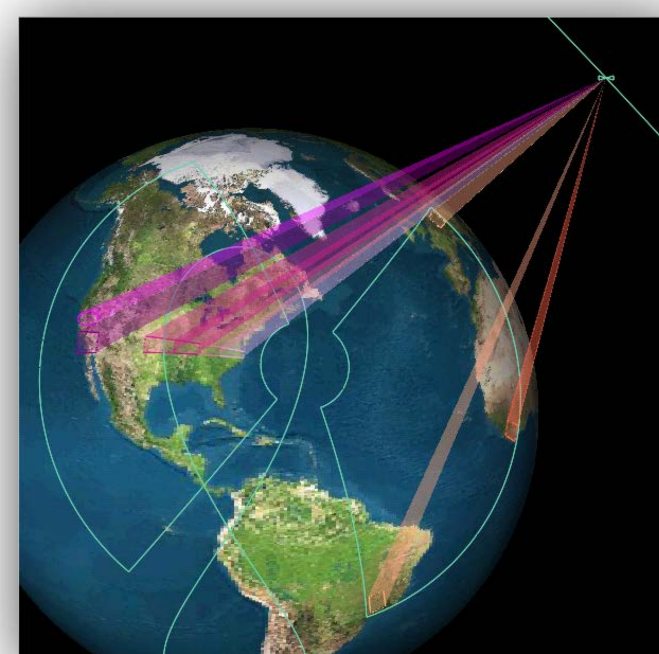

Roll-up SAR Antenna (deployed)


Nearfield Scanner

3x3m Antenna



**Rigid arrays:** 0-20kg/m$^2$ **Membrane arrays:** 2kg/m$^2$, smaller stow volume

# Summary

- Radar at JPL and worldwide is enjoying a period of unprecedented development
- JPL’s science-driven program focuses on exploiting commercially available components to build new technologies to meet NASA’s science goals
- Investments in onboard-processing, advanced digital systems, and efficient high-power devices, point to a new generation of high-performance scientific SAR systems in the US
- Partnerships are a key strategy for US missions in the coming decade