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Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Radar Measurements for Earth Surface Change

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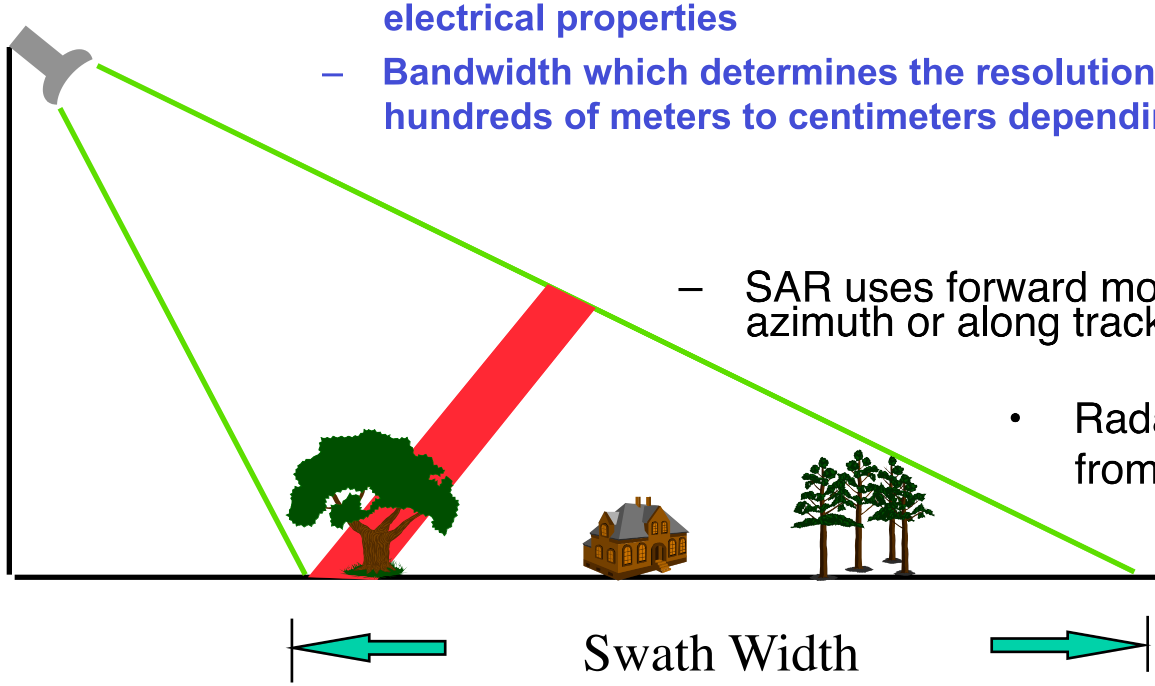
Radar Remote Sensing

- Radar works by emitting microwave radiation from an antenna and recording the energy reflected from objects in the field of view
- The returned radar signal depends on several radar parameters
  - Frequency (wavelength) — radar is most sensitive to objects larger than 1/10 of the radar wavelength. Electrical properties of objects change depending on their material composition and on the wavelength
  - Polarization data which is sensitive to the orientation of objects as well as their electrical properties
  - Bandwidth which determines the resolution of the imagery (it varies from hundreds of meters to centimeters depending on the radar system)



– SAR uses forward motion of antenna to achieve fine azimuth or along track resolution

- Radar imagery may be obtained either from spaceborne or airborne platforms

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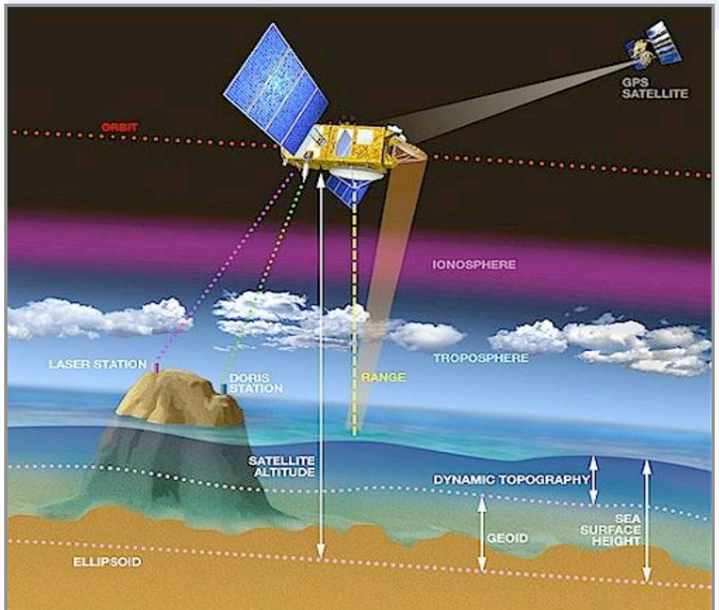
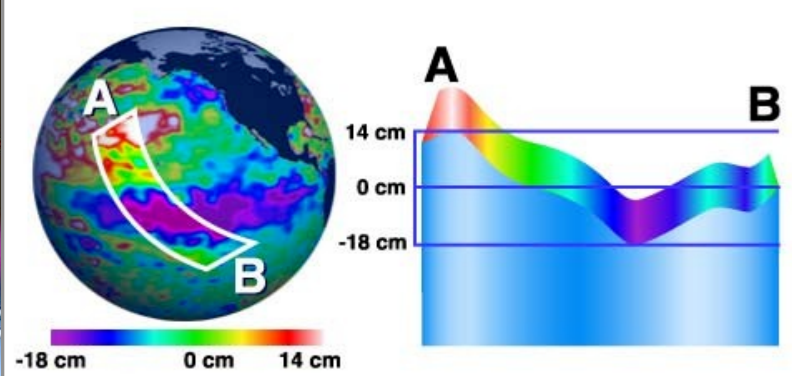
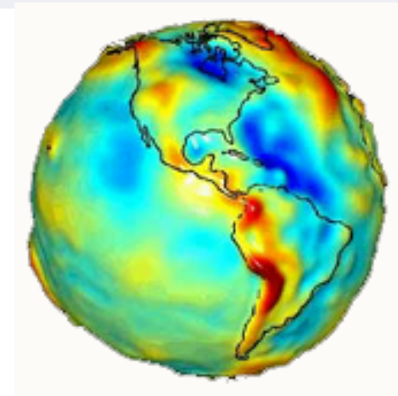
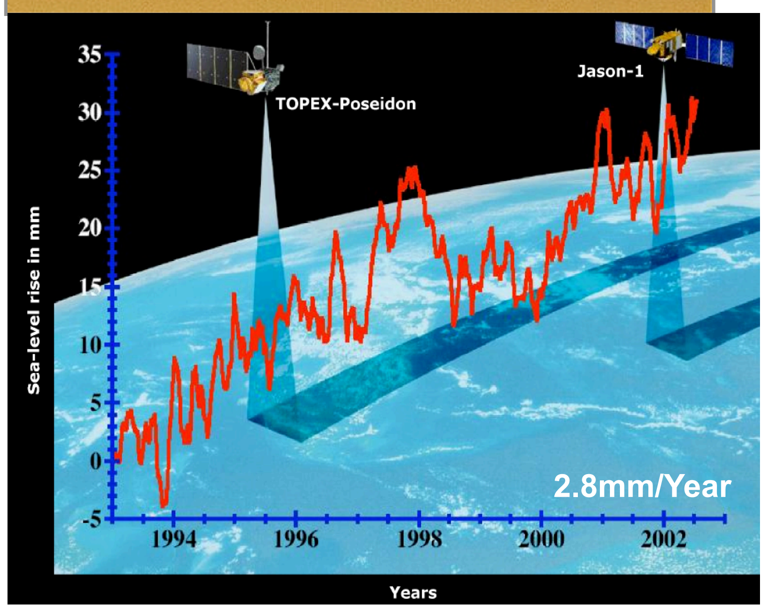
Sea Level Rise using GRACE and Jason/Topex data

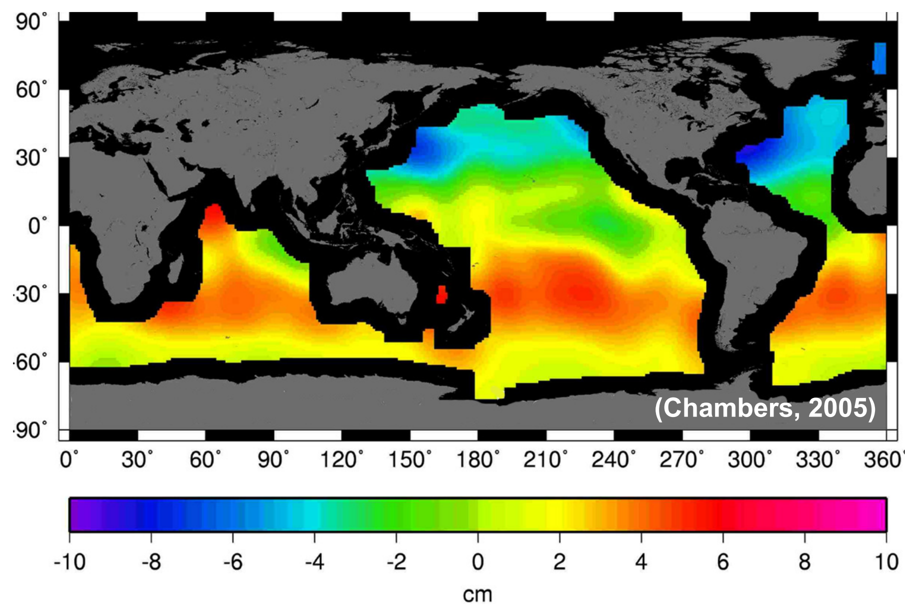




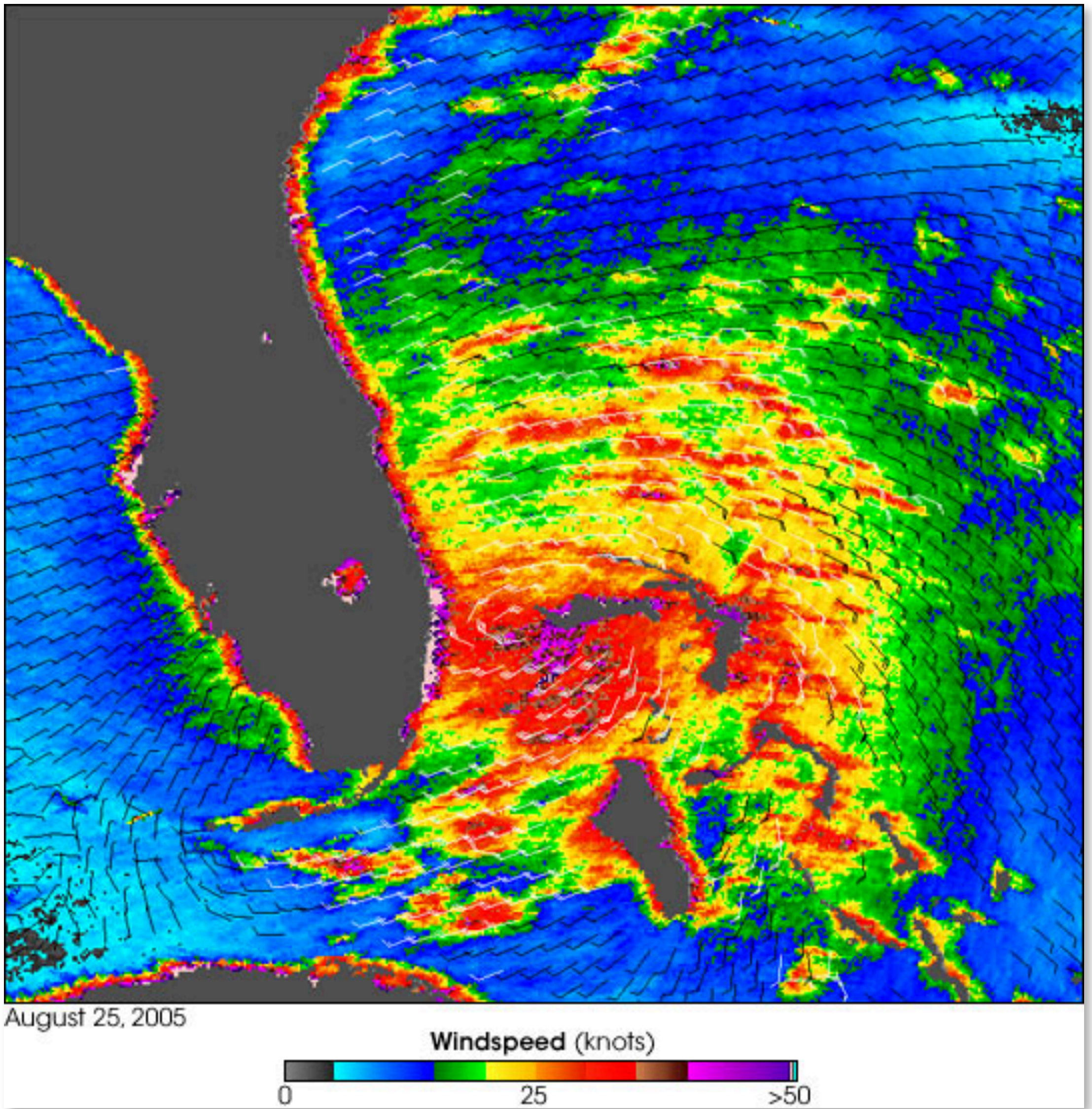


Topex/Jason topography (left)- GRACE mass change (right) = thermal expansion of the ocean (below)





Radar scatterometer sees hurricane Katrina near Florida



- Scatterometers
  - Obtain global wind vectors on a daily basis
    - Research, climatology, weather operations
  - Other applications
    - Ice edge detection, land change detection, snow cover, freeze/thaw detection, flood detection

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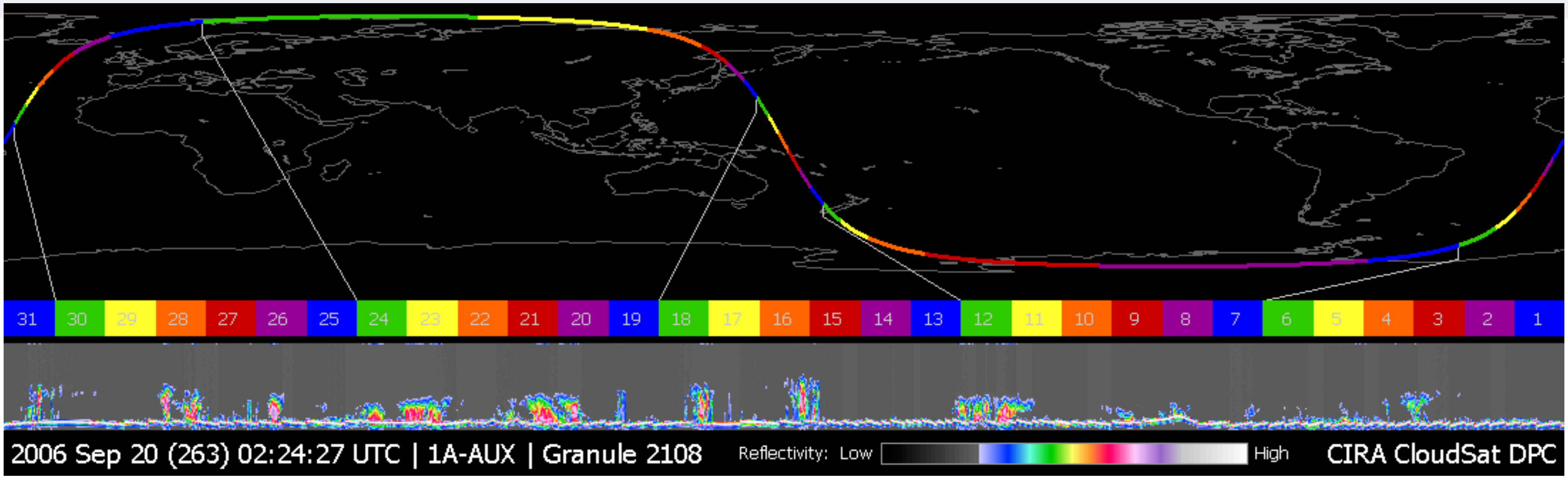
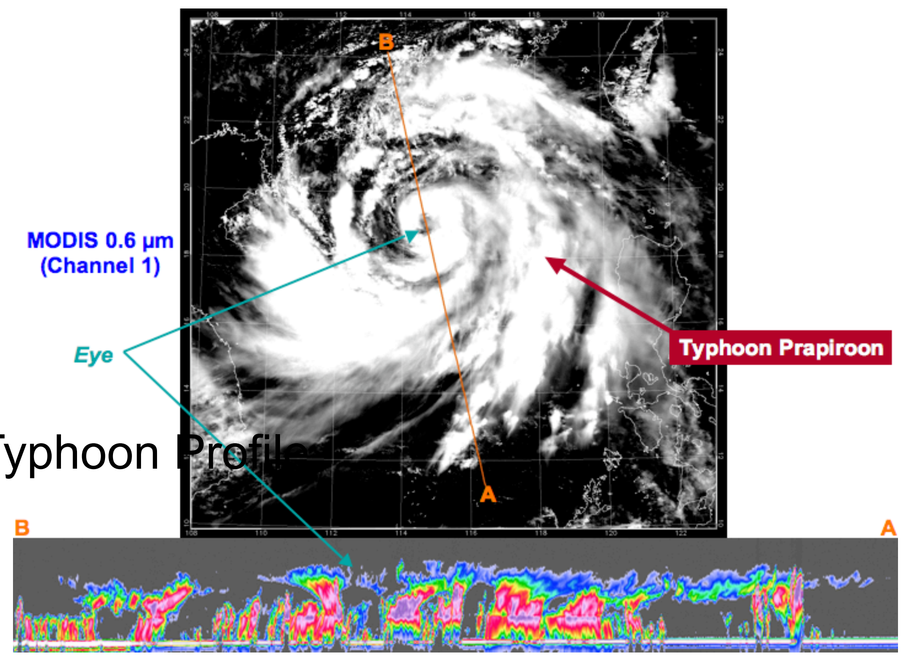
CloudSat 94 GHz Cloud Profiling Radar - On-orbit Quick-look Data

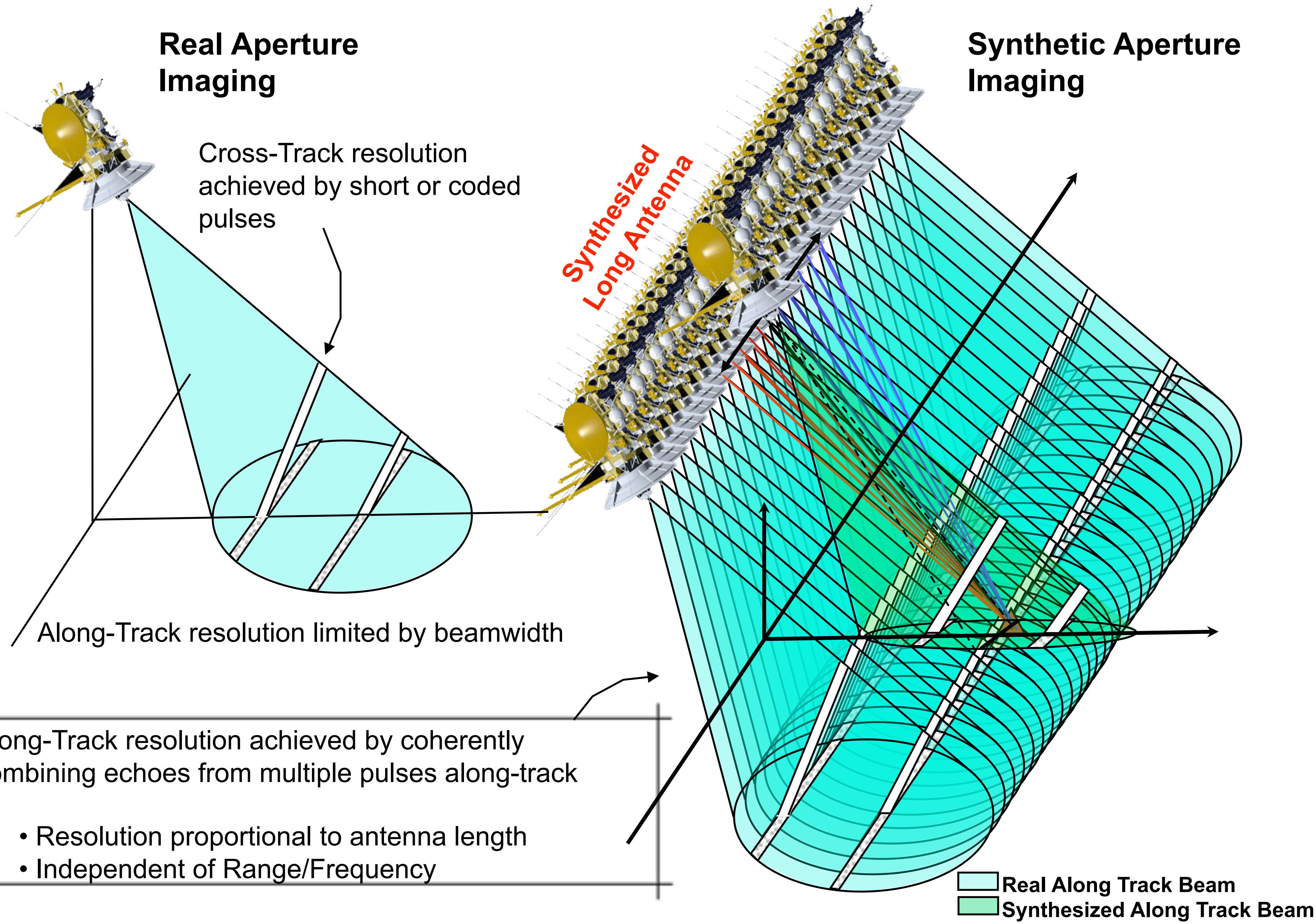


Typical Orbital Profile



Typhoon Profile

SAR Imaging Concept



Along-Track resolution achieved by coherently combining echoes from multiple pulses along-track

- Resolution proportional to antenna length
- Independent of Range/Frequency

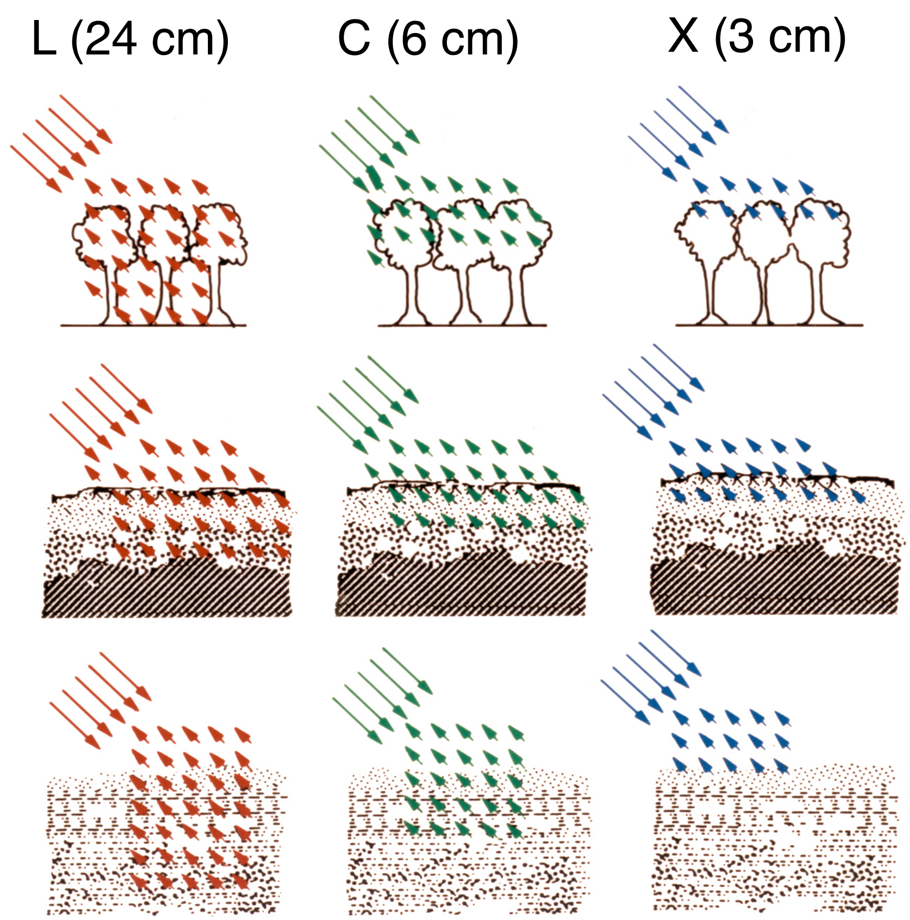
Wavelengths — a Measure of Surface and Subsurface Scale Sizes

Light interacts most strongly with objects on the size of the wavelength.

Forest: Leaves reflect X-band wavelengths but not L-band.

Dry soils: The surface looks rough to X-band but not L-band.

Ice: The surface and layering look rough to X-band but not L-band.



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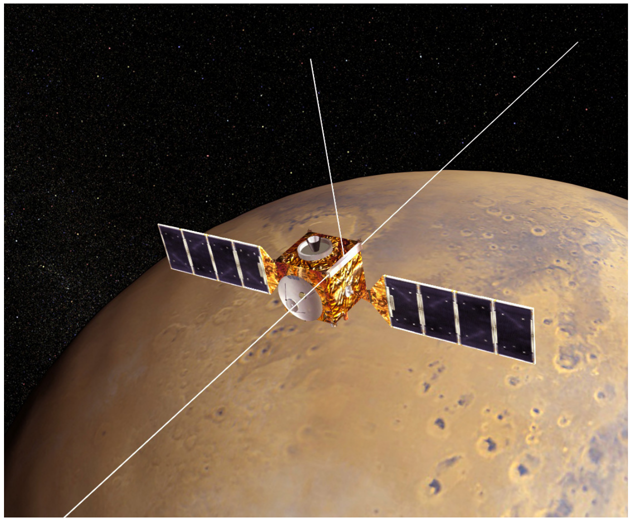
Modeling of Surface and Subsurface Scattering at Long Wavelength

- Radar signal penetrates dry sand, revealing bedrock structure below.
- Correlation of field measurements, data, and electromagnetic simulations yield greatest insight into applicability of techniques in other places
  - Other desert environments
  - Mars and other planetary bodies

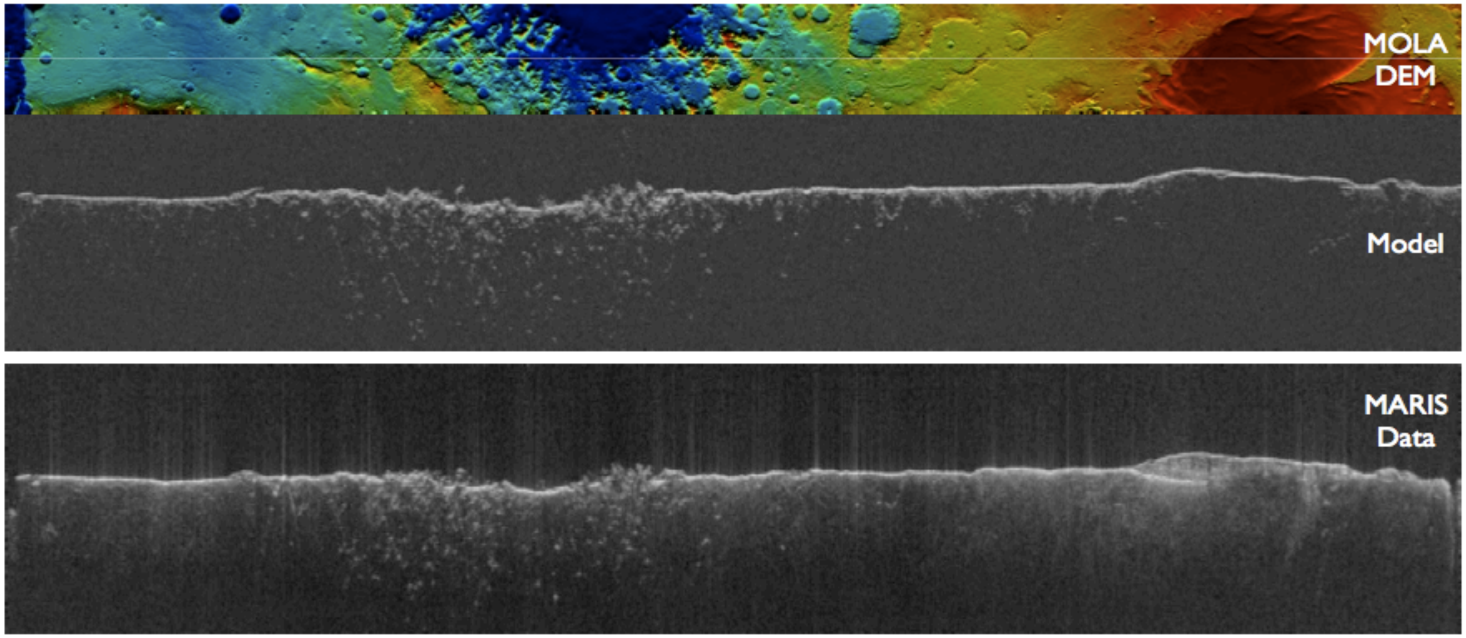
Northwest Sudan: Selma Sand Sheet.

Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) on ESA Mars Express



Mission/Goals

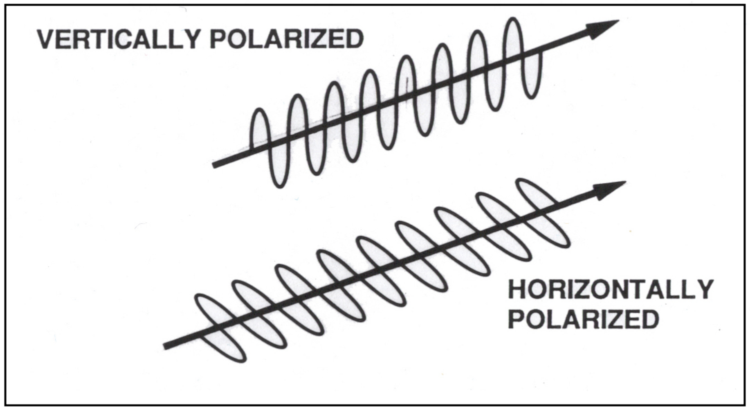
- **Primary Goal: To characterize the surface and subsurface electromagnetic behavior/variation in order to elucidate the geology (Search for water, material property, stratigraphy, structure, etc) at global scales with penetration depth of up to 5 km.**
- **Secondary Goal: To characterize the ionosphere of Mars**



Modeling of surface scattering at very low frequency reveals subsurface features

Polarization — a Measure of Surface Orientations and Properties

Wave Polarization

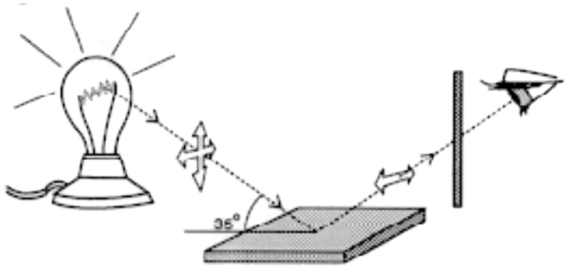


Polarization Filters

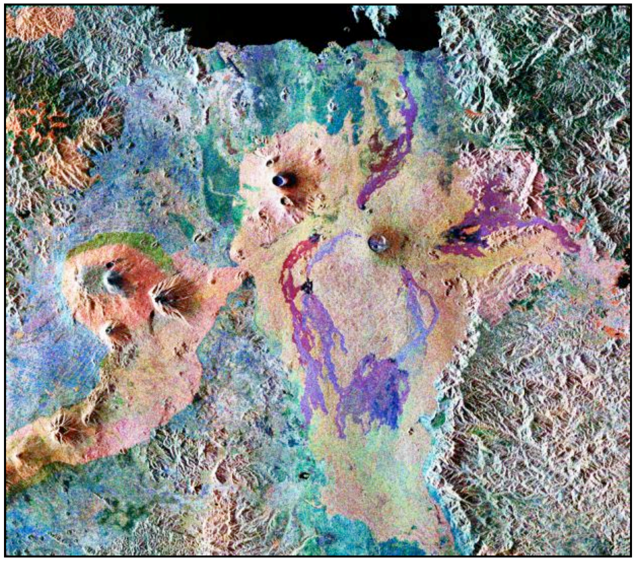
www.colorado.edu/physics/2000

Vertical polarization passes through horizontally arranged absorbers.

Horizontal polarization does not pass through



Mostly horizontal polarization is reflected from a flat surface.

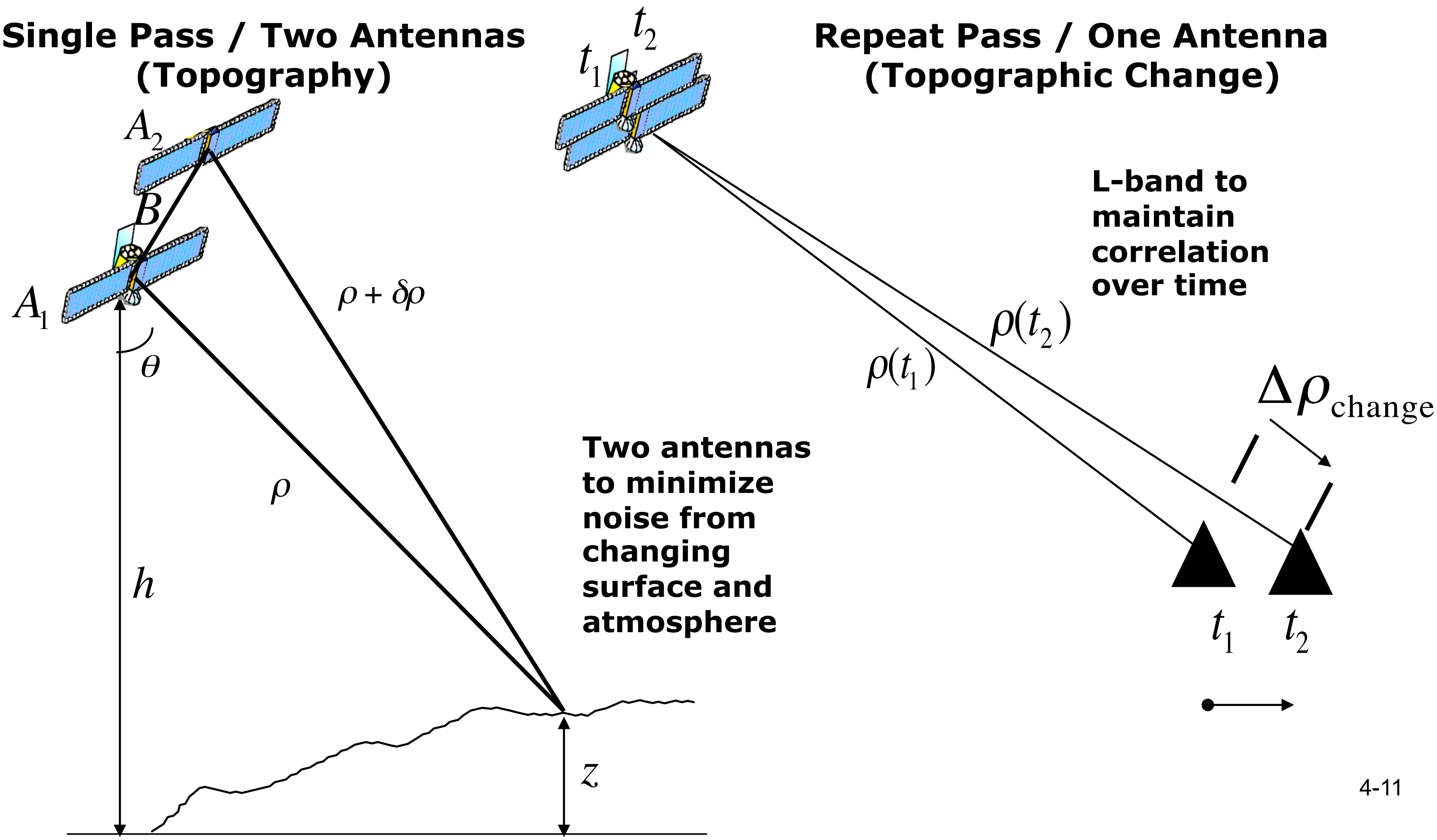


Polarimetry from SIR-C/X-SAR

Interferometry Basics

Single Pass / Two Antennas (Topography)

Repeat Pass / One Antenna (Topographic Change)



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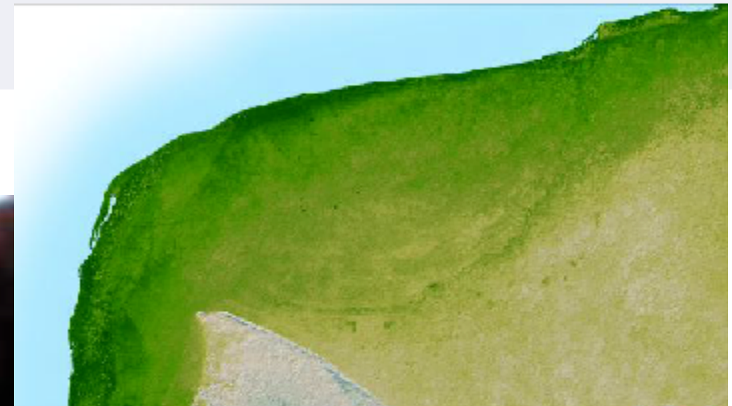
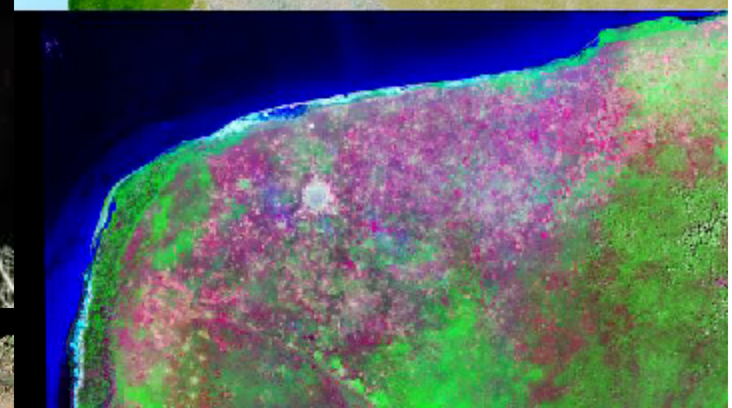
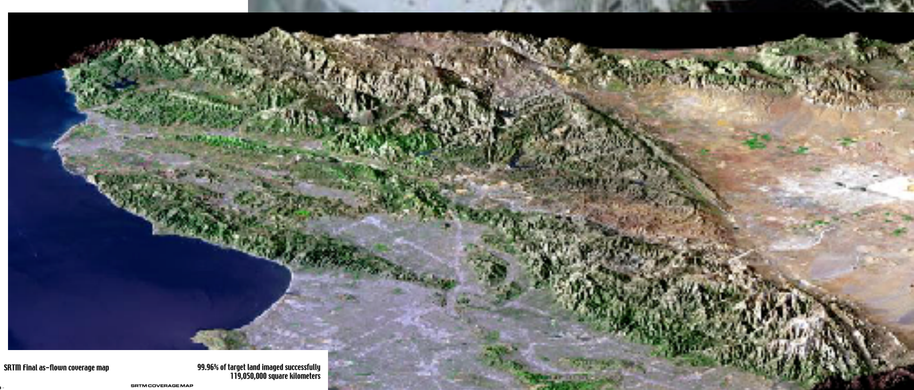
Shuttle Radar Topography Mission (SRTM)

- Mapped 80% of Earth
- 30 m horizontal data points
- 10 m vertical accuracy

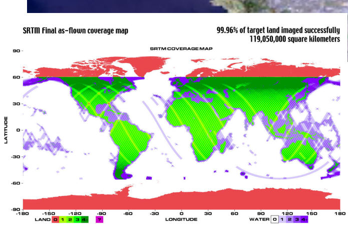


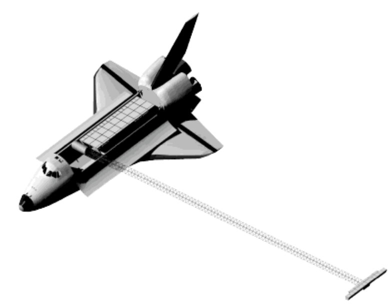


SRTM image of Yucatan showing Chicxulub Crater, site of K-T extinction impact. Bottom image is from Landsat showing Merida



3-dimensional SRTM view of Los Angeles (with Landsat data) showing San Andreas fault





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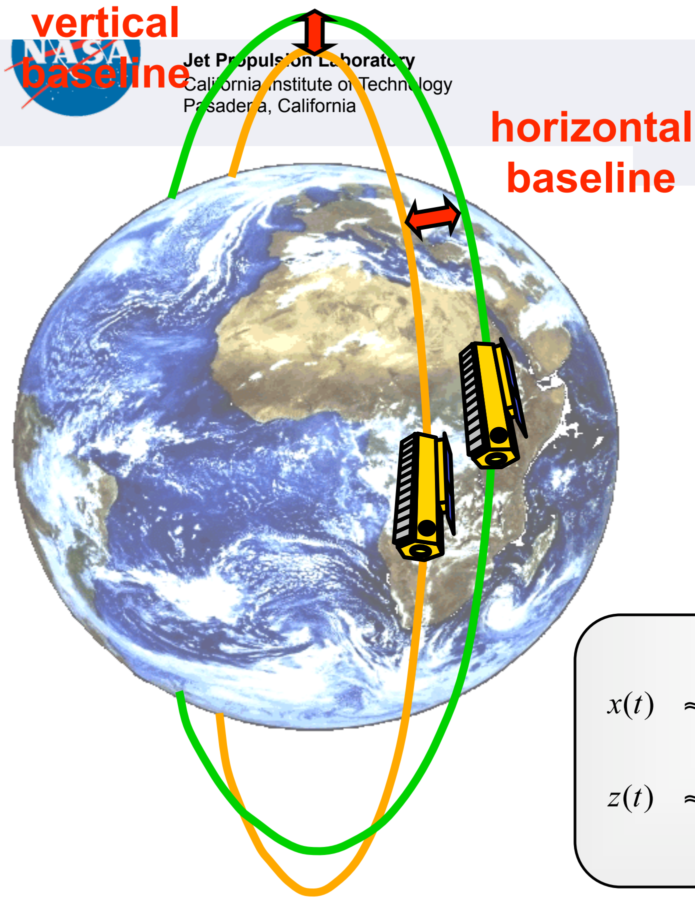
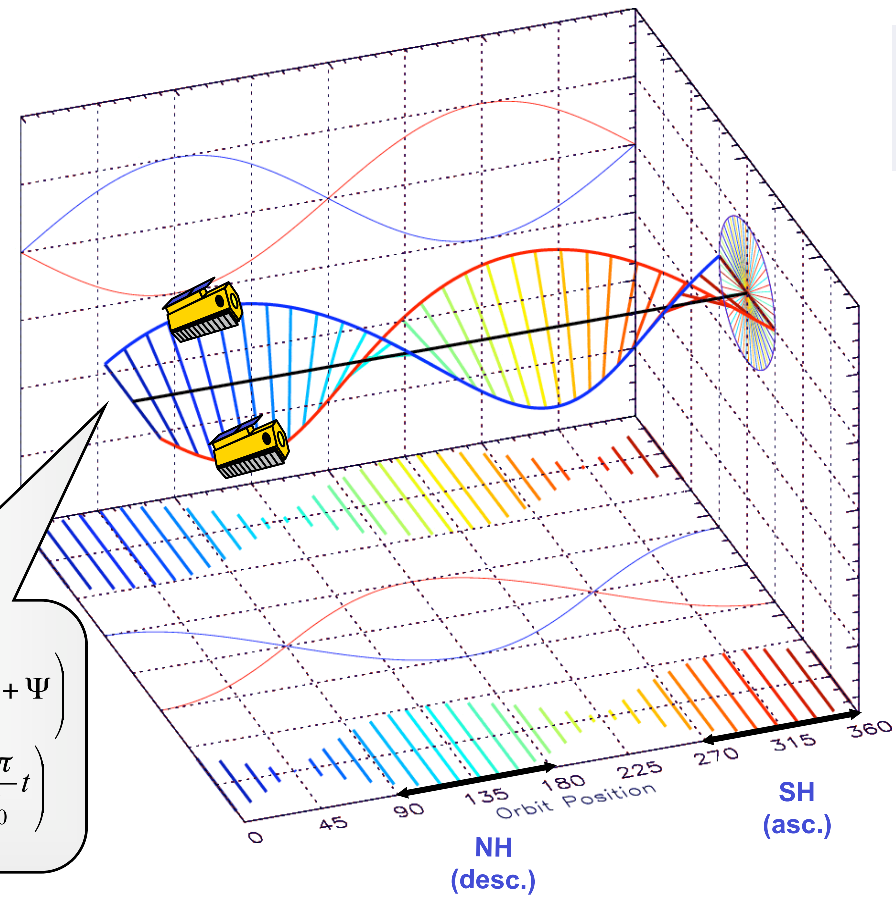
Tandem-X/L HELIX Formation





$$x(t) \approx a \cdot \Delta e \cdot \sin\left(\frac{2\pi}{T_0} t + \Psi\right)$$

$$z(t) \approx a \cdot \Delta\Omega \cdot \cos\left(\frac{2\pi}{T_0} t\right)$$

HELIX satellite formation enables safe operation

- *horizontal cross-track separation at equator by different ascending nodes*
- *vertical (radial) separation at poles by orbits with different eccentricity vectors (periodic motion of libration has to be compensated by regular manoeuvres)*

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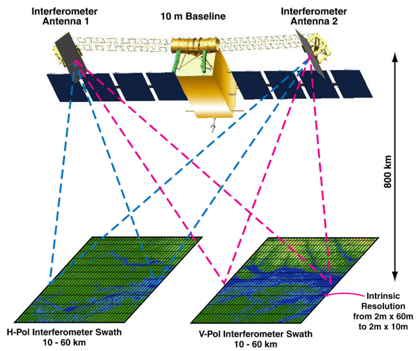
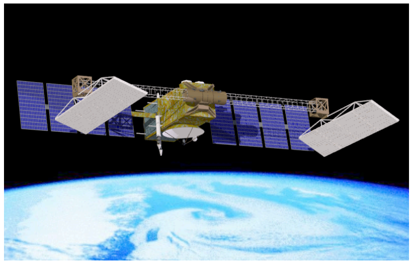
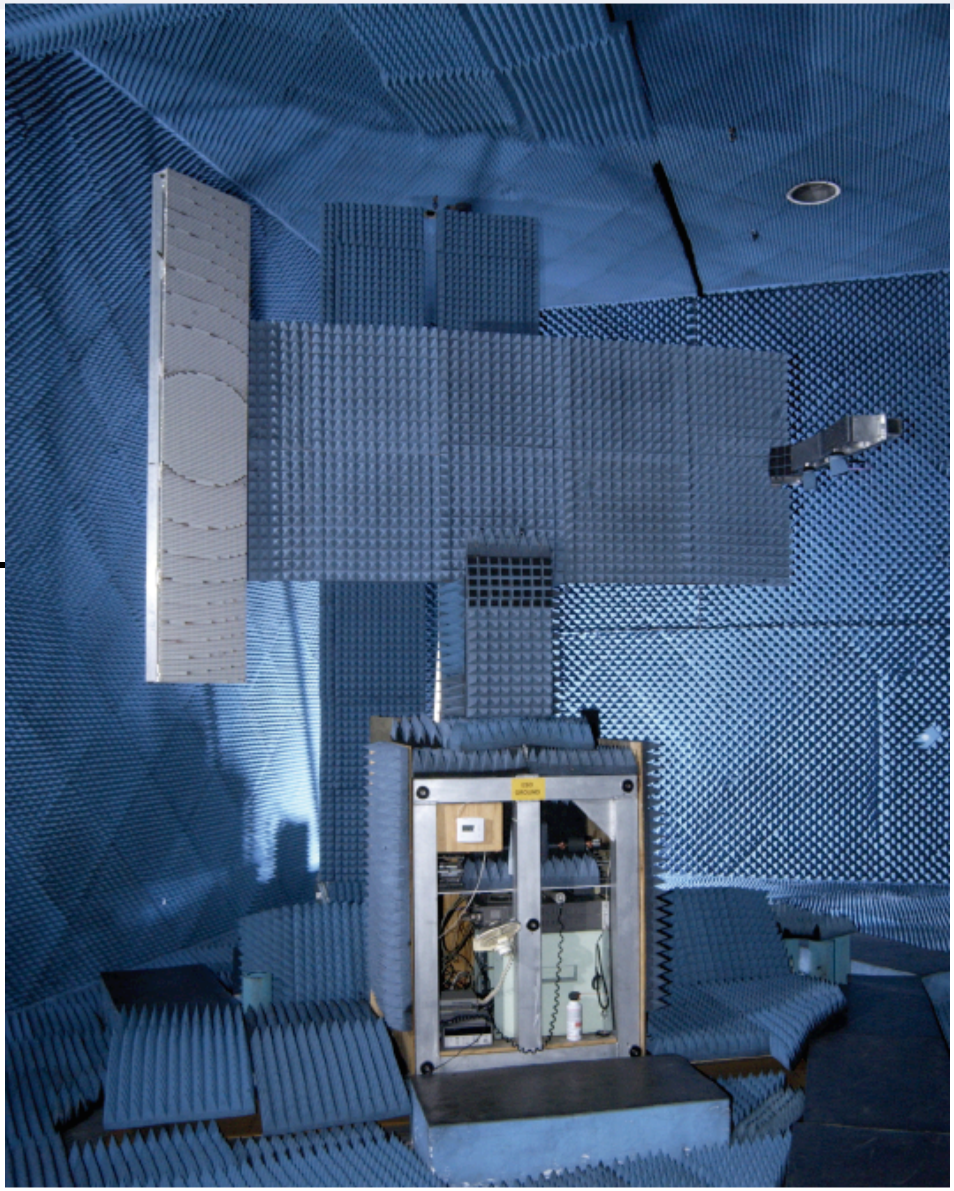
JPL Ka-band Radar Interferometry



KaRIN concept for mapping surface water & ocean topography (SWOT)

Ka-band InSAR for glacier and land ice surface topography (GLISTIN)





Technologies:

- Ka-band center frequency to minimize electronics mass & volume
  - Mass varies by system design, but as low as 25 kg
  - Power usage varies by system design, but as low as 150 W.
  - Onboard processing can reduce data rate to as low as 2 Mbps.
- Significant re-use of technologies developed for JPL Ka-band altimeter / velocimeter, including:
  - Low-power, millimeter-wave hybrid front-end circuitry
  - Wide bandwidth analog design, with digital filtering & downconversion
- Additional heritage from JPL Wide Swath Ocean Altimeter development effort
  - Antenna / feed system
  - Algorithms for achieving centimetric height accuracy

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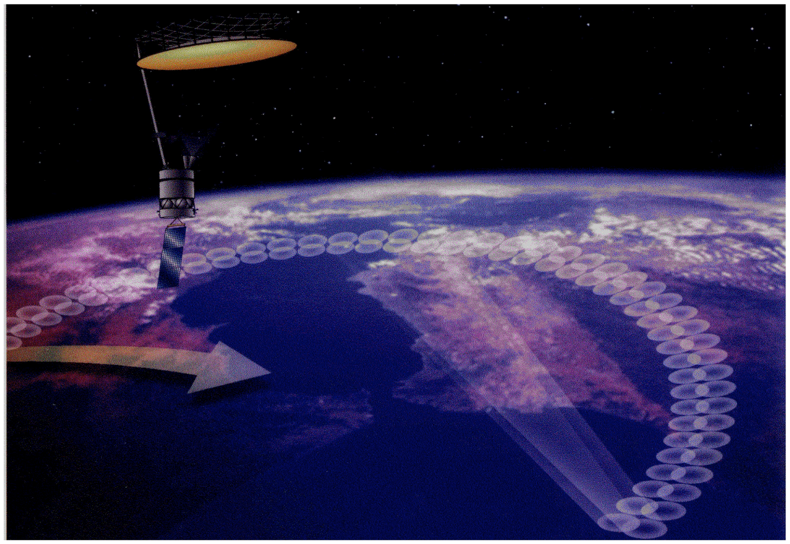
Soil Moisture Mission Concept

Recommended by NRC decadal survey for early launch



Science Questions

Soil Moisture
- How are global precipitation, evaporation, and water cycling changing?
- How are global ecosystems changing?
- What are the effects of clouds and surface hydrological processes on Earth's climate?

Ocean Vector Winds
- How are global precipitation, evaporation, and the cycling of water changing?
- How is the global ocean circulation varying on interannual, decadal, and longer time scales?
- How can weather forecast duration and reliability be improved by new space-based observations, data assimilation, and modeling?

Precipitation
- How can weather forecast duration and reliability be improved by new space-based observations, data assimilation, and modeling?

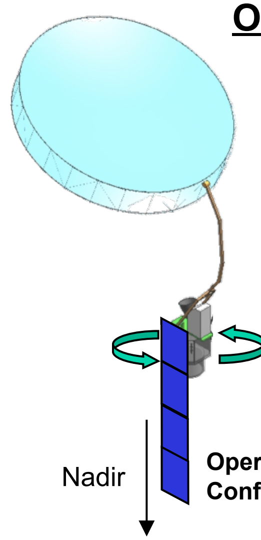
Features of the Mission Concept

- **Launch Mid-2014**
- **Launch Vehicle:**
  - **Baseline: Taurus 3210 (small class)**
  - **Option 1&2: Delta 2320-10 (medium class)**
- **Orbit: ~98° Inc., 670 km Alt., 3 day quasi repeating ground track, 6 am acsending**
- **Mission Duration: 2 years (All Options)**
- **Payload: L-band radar and radiometer (HYDROS) (Baseline); + Ku-band radar (Option 1); +C-band radar and C,X,K,Ka-band radiometers (Option 2)**
- **Payload Avg. Power: 400W (Baseline) – 1332W (Option 2)**
- **Payload Mass: 233 kg (Baseline) – 445 kg (Option 2)**
- **Pointing: Within 0.1 deg to Nadir (Control); 0.05 deg (knowledge)**
- **Downlink Rate: 80 Mbps (Baseline) – 320 Mbps (Option 2)**

Technology Development Needs

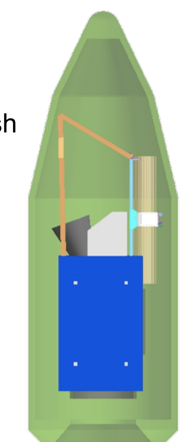
- **Radar Electronics/Feed/Reflector spinning assembly**

Observatory Concept

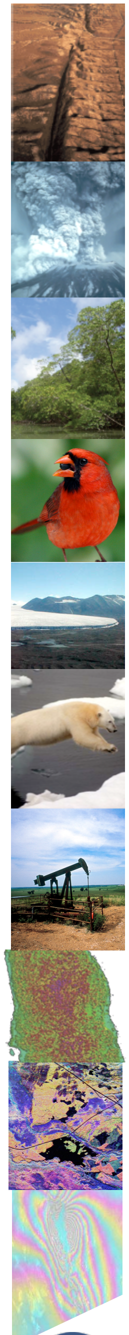


Operational Configuration

- 6m diameter deployable mesh reflector
- Spinning Radar assembly (including electronics, feeds and reflector)
- 15 rpm spin rate around the nadir axis

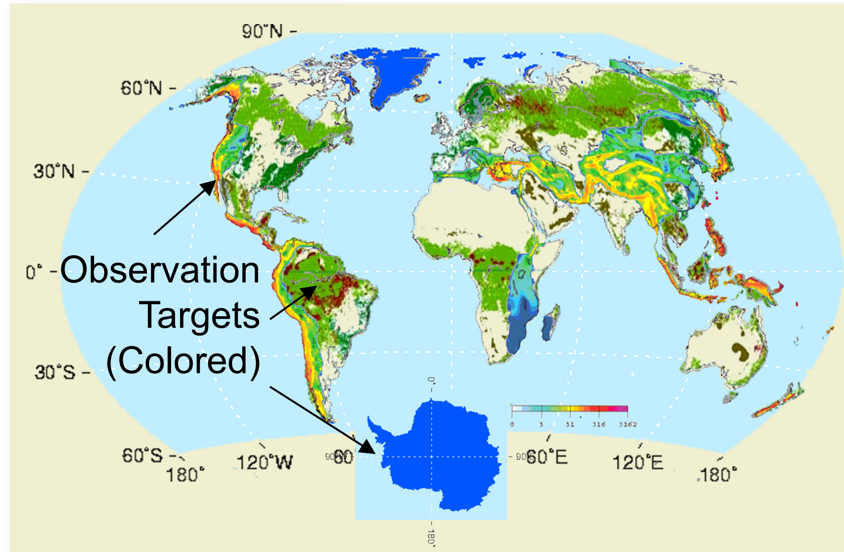


Launch Configuration

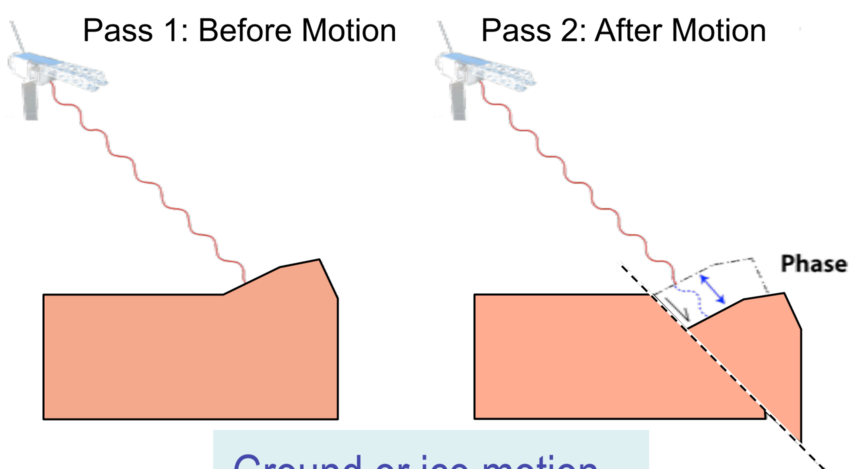


DESDynI: Deformation, Ecosystem Science, and Dynamics of Ice

- Recommended by the NRC Decadal Survey for near-term launch to address important scientific questions of high societal impact:
- How do we manage the changing landscape caused by the massive release of energy of earthquakes and volcanoes?
- How are Earth's carbon cycle and ecosystems changing, and what are the consequences?
- What drives the changes in ice masses and how does it relate to the climate?

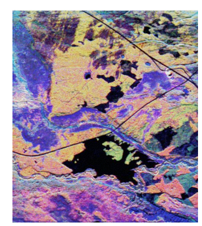


Repeat Pass InSAR

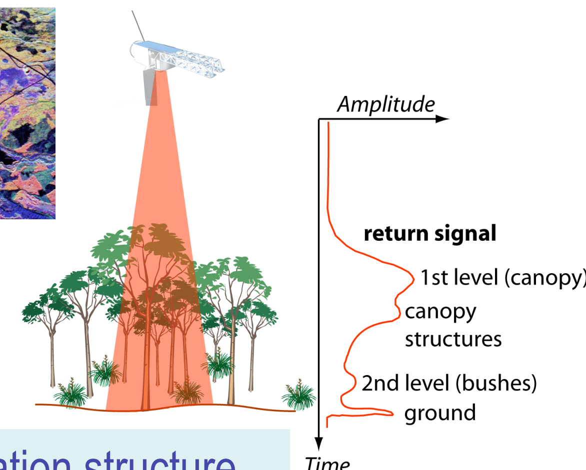


Ground or ice motion

Polarimetric SAR

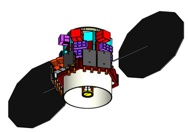


Multibeam LIDAR

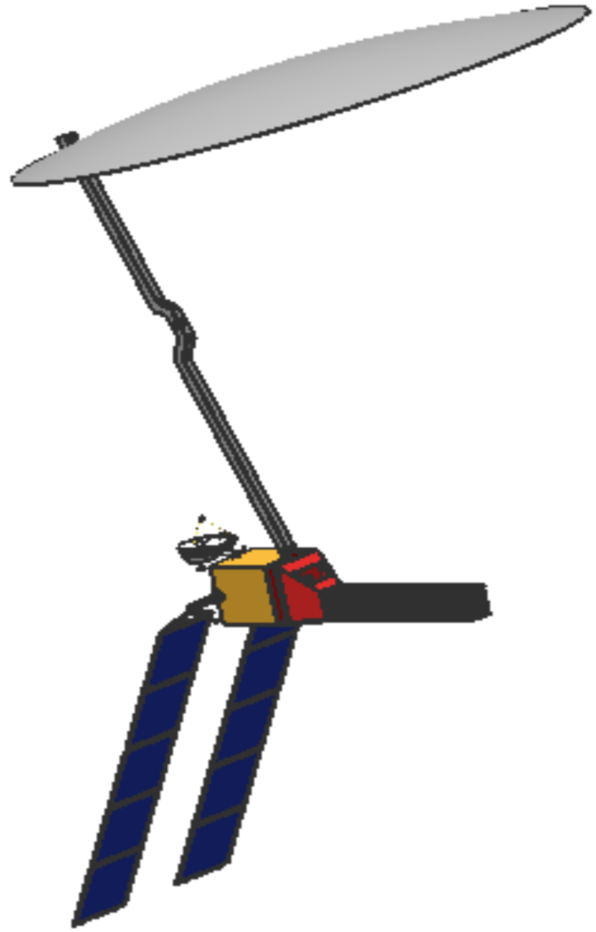


Vegetation structure

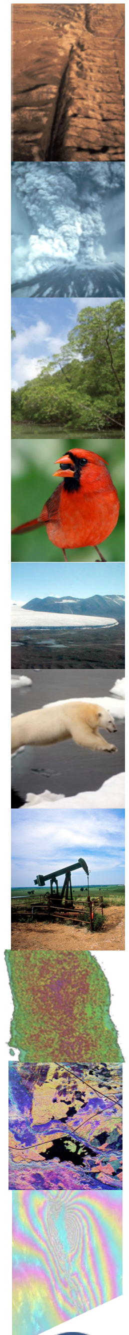
DESDynI Two-Platform Configuration



Lidar-craft

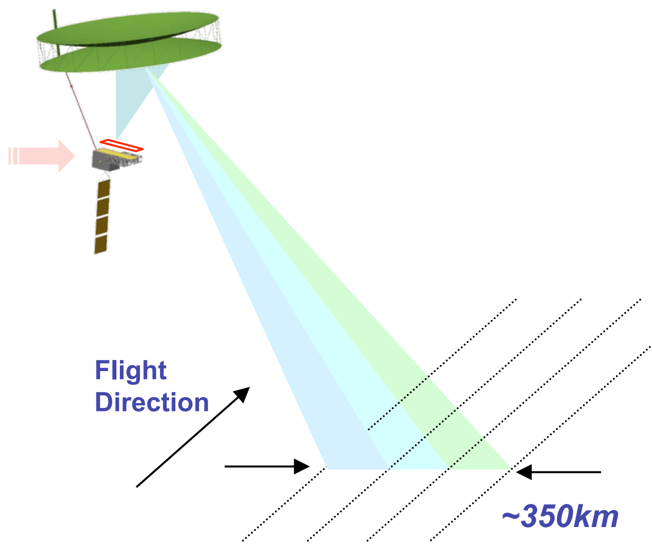


Radar-craft



DESDynI Instruments

L-Band Synthetic Aperture Radar

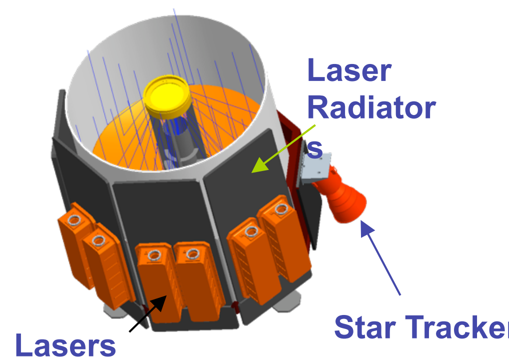


Technology

Key advanced technology investments have already been made

- L-band TR modules, antenna designs, trade studies, and modeling and simulation
- Under ESTO, UAVSAR system for quad-pol InSAR from aircraft
- Detailed engineering and packaging tasks remain

Multi-beam Lidar

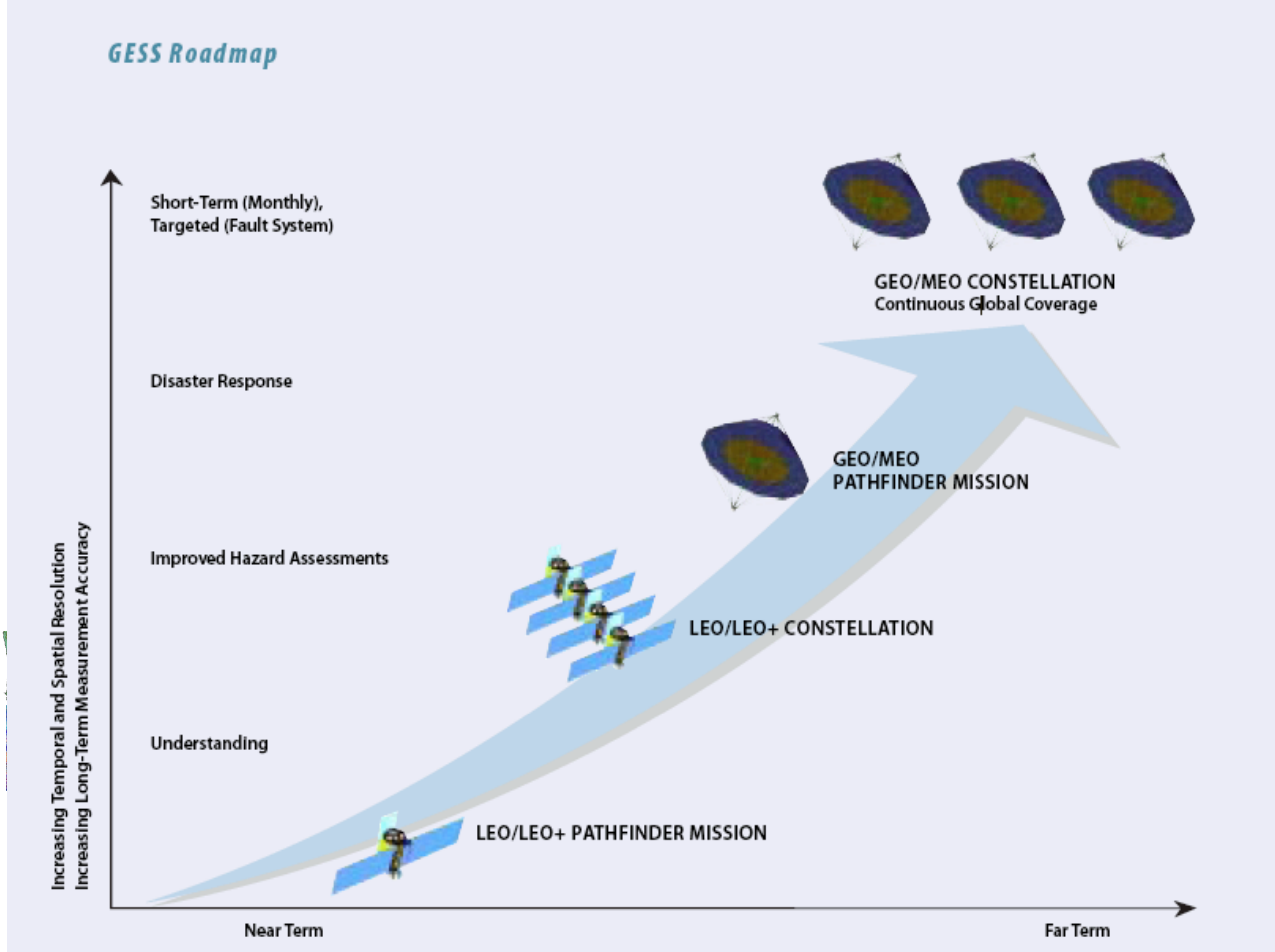


- Lasers,Telescope, Gyro, and Star Tracker all tightly-coupled on composite optical bench
- Primary mirror diameter: 1.2m

Technology

Laser transmitter is currently at TRL 6*:

- GSFC-designed full waveform HOMER laser tested to full flight performance requirements (output power, rep rate, beam quality, efficiency, and lifetime)
- All components space qualified (TRL 6 or higher)
- Testing of laser ETU verifying the Multi-Beam Lidar performance in a relevant environment (vibration, thermal vacuum, etc.) to TRL 6.
- Detailed engineering and packaging tasks remain


GESS Roadmap
Short-Term (Monthly),
Targeted (Fault System)
Disaster Response
Improved Hazard Assessments
Understanding
Increasing Temporal and Spatial Resolution
Increasing Long-Term Measurement Accuracy
GEO/MEO CONSTELLATION
Continuous Global Coverage
GEO/MEO
PATHFINDER MISSION
LEO/LEO+ CONSTELLATION
LEO/LEO+ PATHFINDER MISSION
Near Term
Far Term