Radar Technology Status

for Surface Topography and Vegetation

Yunling Lou, Jet Propulsion Laboratory, California Institute of Technology
(Radar Technology Lead)

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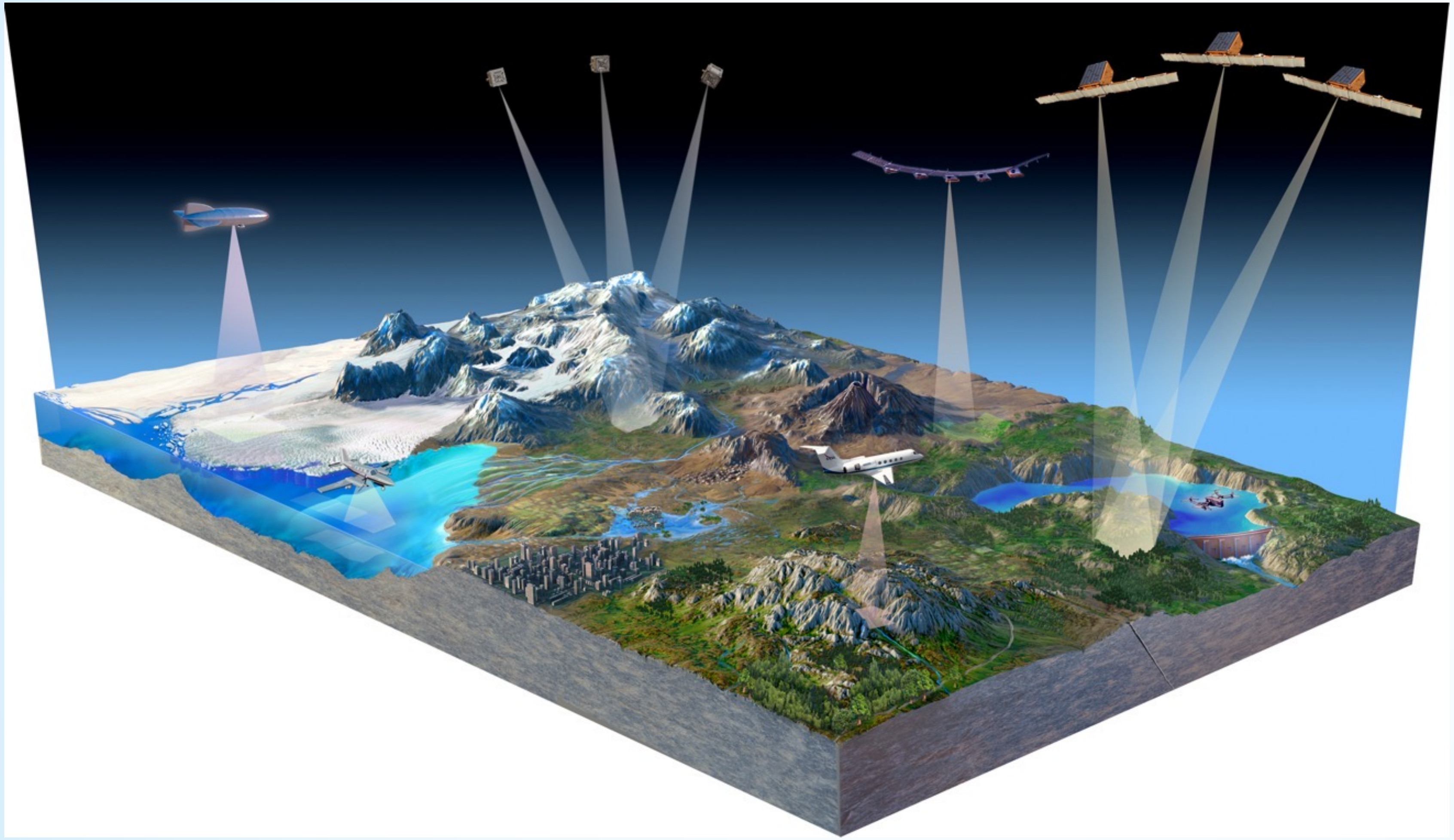
November 14-15, 2023

Jet Propulsion Laboratory
California Institute of Technology

Outline

- Review of radar-related findings from the incubation study report
- Current and funded spaceborne radar missions
- Commercial spaceborne radar constellations
- Operational airborne radar assets
- Funded radar projects
- Radar technology/measurement gaps

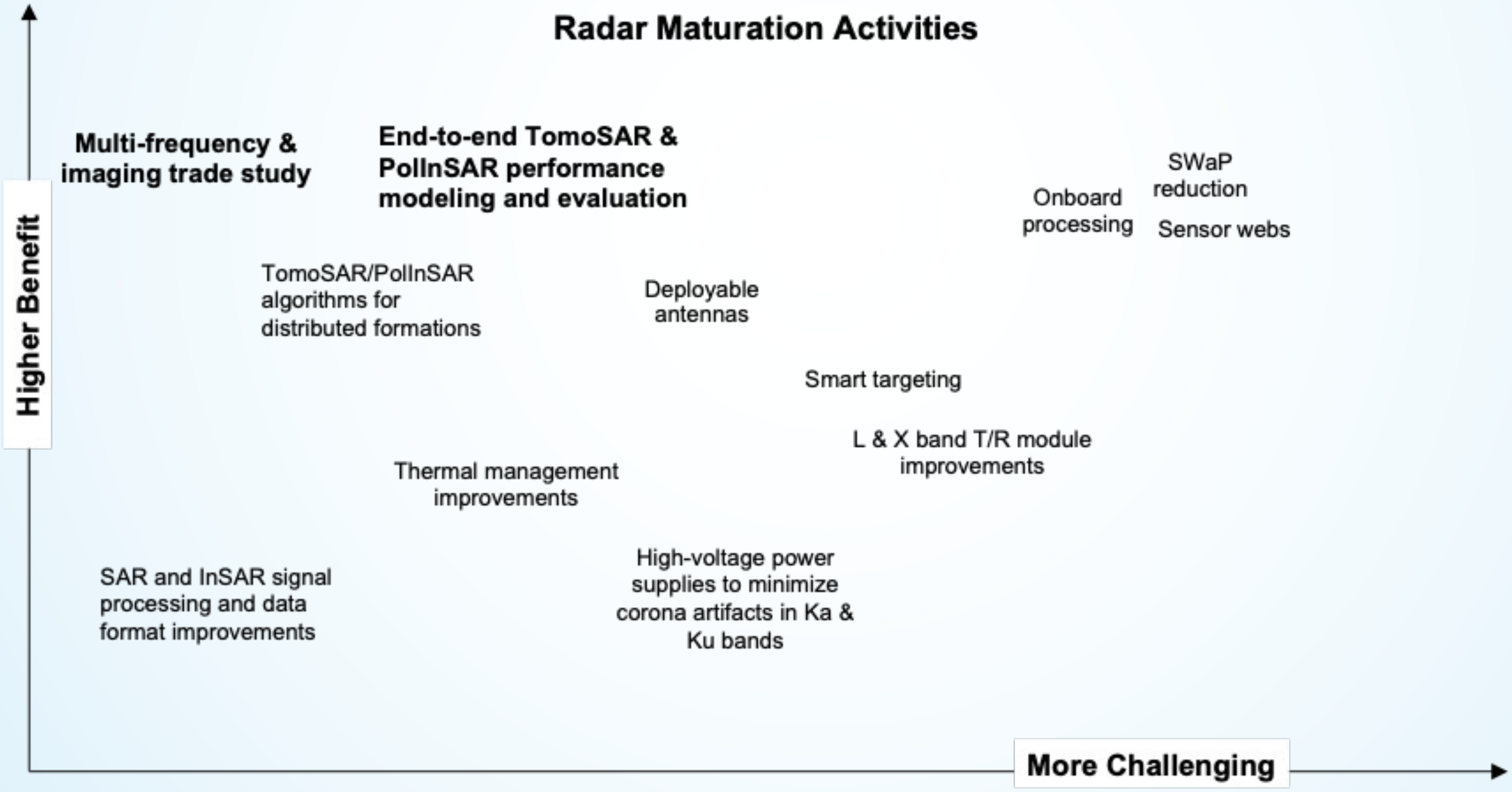
STV Multi-Platform Observation Concept



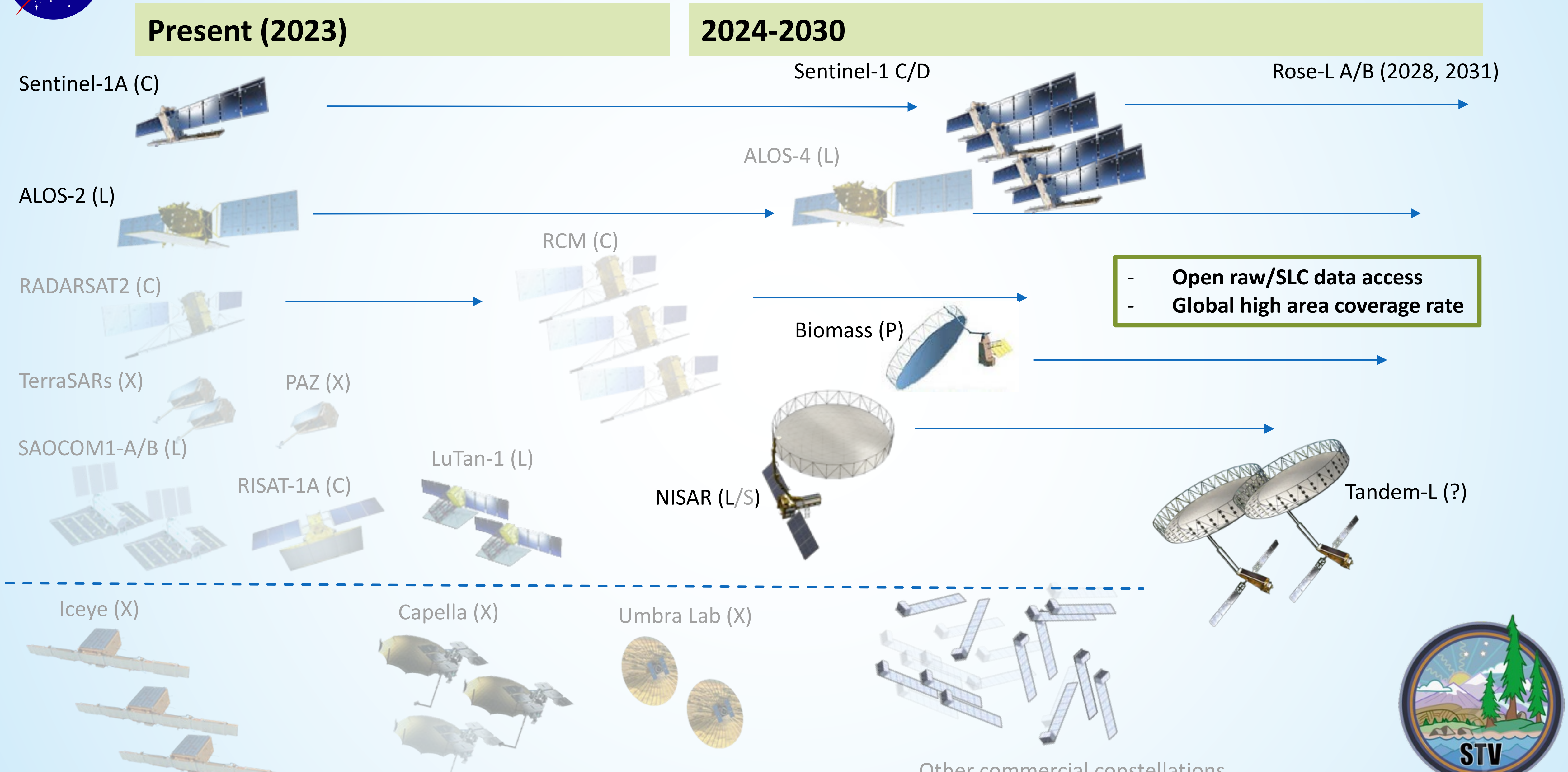
- InSAR for global topo-mapping
- TomoSAR with multiple small satellites for vegetation/sub-surface structure
- HALE or Airship-based persistent observation of rapidly evolving events
- Flexible airborne observation for high resolution 3D imaging

STV Incubation Study Report for Radar Technology (2021)

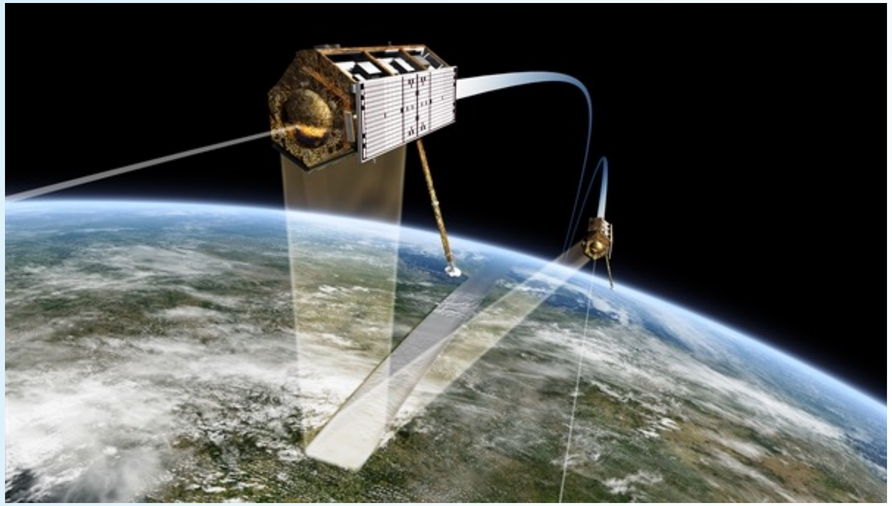
- Multifrequency and imaging trade study
- End-to-end TomoSAR and PolInSAR performance modeling and evaluation
- Not mentioned: cross-platform radar synchronization and calibration

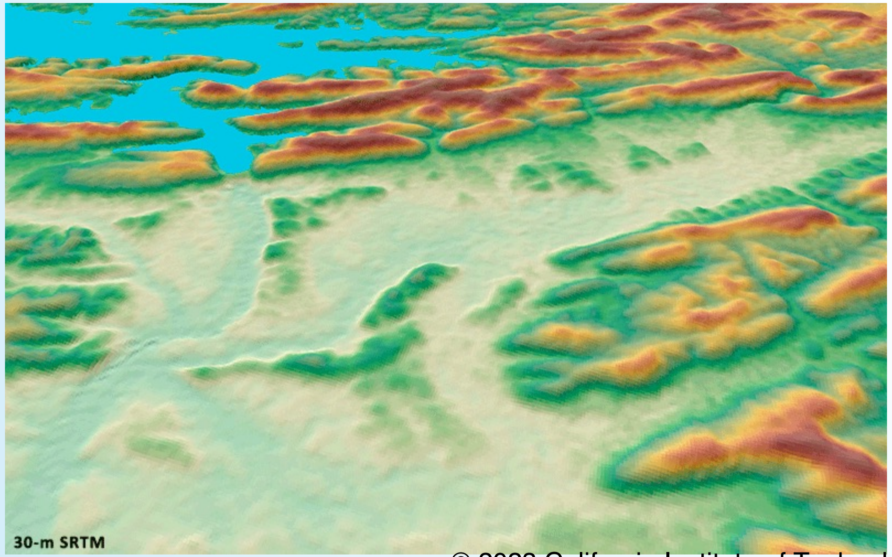


State and Commercial SAR Satellites



Operational Spaceborne InSAR for Topography Mapping -- TanDEM-X (DLR & AirBus)





- Consists of two TerraSAR-X satellites, launched in 2007 and 2010 respectively, flying in formation separated by a few hundred meters
- Spacecraft mass: 1220 kg
- DEM with 12-m horizontal resolution
  - Height accuracy: < 2 m relative (slopes ≤ 20%), < 4 m absolute
  - Absolute horizontal accuracy: < 10 m
- Copernicus DEM 90-m posting is open access
  - Copernicus may release 30-m posting DEM soon
- AirBus' WorldDEM was completed in 2016 features 12-m resolution, and is available for purchase
  - Price per Sq Km: $6.25
  - ($77k per 1º tile at the equator, $65k per 1º tile at 32º latitude)
- **Derivative products: Global Forest/Non-Forest Map, Global Height Change Map**
- DLR has no plans for next generation TanDEM-X
- TanDEM-X End-of-Life date: 31 December, 2026

Taskable Airborne SAR Systems for STV

	Current		Future	
Instrument	Configurations	Capabilities	Configurations	Capabilities
UAVSAR (NASA)	P- & L-band polarimetric DInSAR, Ka-band HH TopSAR	Surface deformation change detection, vegetation structure, volcano topography, ice/snow topography	P/L/S-band polarimetric DInSAR, L/X-band pol. TopSAR, Ka-band HH TopSAR	Surface deformation change detection, vegetation structure, DTM and DSM, ice/snow topography
Intermap	P-band PolSAR & X-band TopSAR	Sub-canopy feature mapping & DSM		

Funded Radar Projects

Project	PI	Gaps being addressed
A Flexible Configuration Distributed Synthetic Aperture Digital Beamforming Radar (FlexDSAR) (IIP)	Yunling Lou, JPL	Distributed DBFSAR with Inter-platform clock synch & calib.
HALE InSAR for Continual and Precise Measurement of Earth's Changing Surface (IIP)	Lauren Wye, Aloft Sensing, Inc.	InSAR algorithm & low SWaP electronics for HALE INSAR
Embedded PNT Module for Distributed Radar Sensing (DSI)	Patrick Rennich, Aloft Sensing, Inc.	Position/Navigation/Timing (PNT) module
An OSSE Framework for STV Multi-Mission Design and Performance Evaluation (DSI)	Marco Lavalle, JPL	Tomo/PolInSAR performance with smallsat formations
Multi-Sensor Multi-Platform Surface Topography and Vegetation Structure Data Fusion Information System (STV-FIS) (DSI)	Sassan Saatchi, JPL	TomoSAR visualization
New Observing Strategies for Beach and Dune Topography and Implications for Coastal Flood Risk (DSI)	Pietro Milillo, U. of Houston	InSAR/Lidar/Photog. data fusion for dunes and coastal processes
Quantifying Bias and Uncertainty Sources between Laser and Radar Retrievals of Surface Topography Over Cryo Targets (DSI)	Matthew Siegfried, Colorado S. of Mines	Radar/Lidar fusion bias & uncertainty for cryo targets
Assessing the Sensitivity and Measurement Needs of Surface Topography Towards the Study of Earthquake and Fault Creep Processes (DSI)	Zhen Liu, JPL	Measurement sensitivity for earthquakes & faults
Extraction of Forest AGB from Logarithms of TomoSAR Profiles	Robert Treuhaft, JPL	TomoSAR algorithm for forest

STV Radar Subgroup Members

Name	Affiliation
Yunling Lou	JPL
Chunli Dai	University of Florida
Tim Dixon	University of South Florida
Bill Hammond	University of Nevada, Reno
Marco Lavalle	JPL
Zhen Liu	JPL
Roger Michaelides	Washington University
Pietro Milillo	University of Houston
Patrick Rennich	Aloft Sensing, Inc.
Mel Rodgers	University of South Florida
Taha Sadeghi Chorsi	University of South Florida
Matthew Siegfried	Colorado S. of Mines
Robert Treuhaft	JPL
Lauren Wye	Aloft Sensing, Inc.
Robert Zinke	JPL

STV Radar Subgroup Members

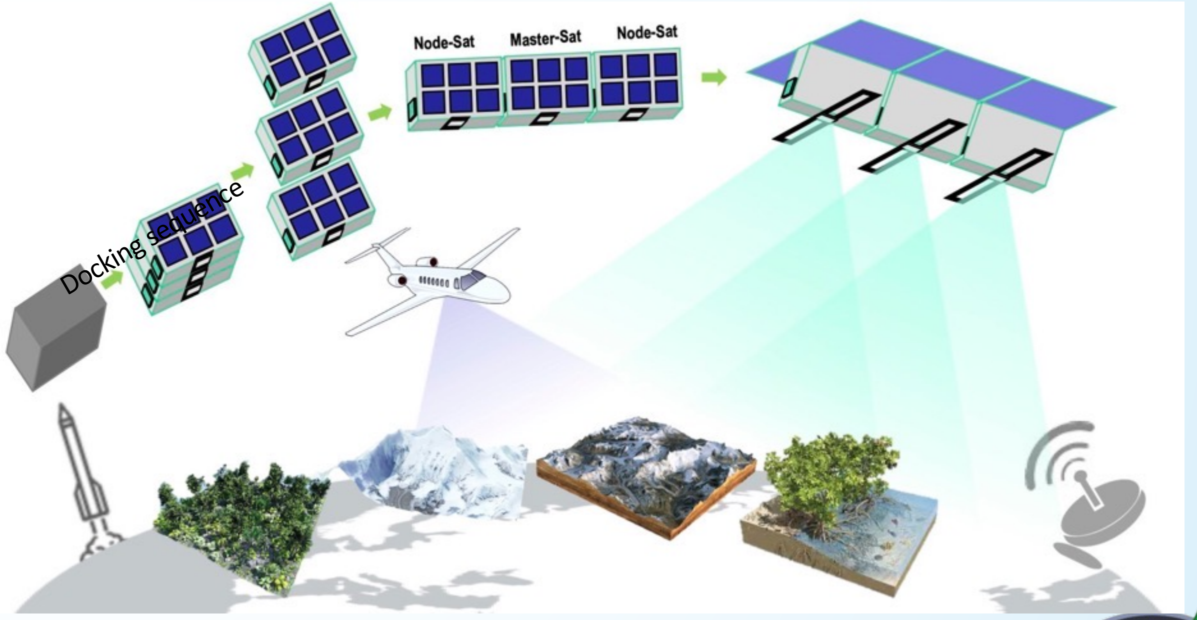
FirstName	LastName	EmailAddress	SE	V	C	H	CG	A	R	L	S	O	P	AS
Chunli	Dai	chunlidai@ufl.edu	SE						R					
Timothy	Dixon	thd@usf.edu	SE		C				R					AS
Bill	Hammond	whammond@unr.edu	SE						R	L	S			
Marco	Lavalle	marco.lavalle@jpl.nasa.gov		V					R			O		
Zhen	Liu	Zhen.Liu@jpl.nasa.gov	SE			H		A	R	L	S			
Yunling	Lou	yunling.lou@jpl.nasa.gov		V		H		A	R			O	P	
Roger	Michaelides	roger.michaelides@wustl.edu	SE		C				R	L				
Pietro	Milillo	pmilillo@uh.edu			C		CG	A	R					
Patrick	Rennich	patrick.rennich@aloftsensing.com							R					
Mel	Rodgers	melrodgers@usf.edu	SE				CG	A	R	L	S			
Taha	SadeghiChorsi	taha4@usf.edu	SE				CG	A	R	L				
Matt	Siegfried	siegfried@mines.edu	SE		C		CG		R	L				
Robert	Treuhaft	robert.treuhaft@jpl.nasa.gov		V					R	L		O		
Lauren	Wye	lauren.wye@aloftsensing.com	SE	V				A	R			O	P	AS
Robert	Zinke	robert.zinke@jpl.nasa.gov	SE					A	R		S			

Project summaries

FlexDSAR IIP Project Overview

PI: Yunling Lou (yunling.lou@jpl.nasa.gov)
Co-Is: Brian Bachman Okihiro, Jack Bush, Duane Clark, Xueyang Duan (JPL); Mahta Moghaddam (USC)

- Design an architecture that is suitable for implementation on low cost distributed platforms, achieving a ***large synthetic aperture via docking of multiple small satellites***.
- Develop ***digital beamforming electronics*** that are flexible and scalable across a large frequency range including P & L-band, reconfigurable for different imaging modes, and reconfigurable for resolution, and spatial coverage.
- Leverage FlexDSAR technology to upgrade UAVSAR to generate science quality products to help mature technology and science algorithms in support of STV studies --> ***AIRSAR-NG capable of multi-platform imaging***
- Conduct multi-frequency and imaging trade study by building a unified EM-based simulation environment for sensitivity analyses to arrive at optimal observation scenarios



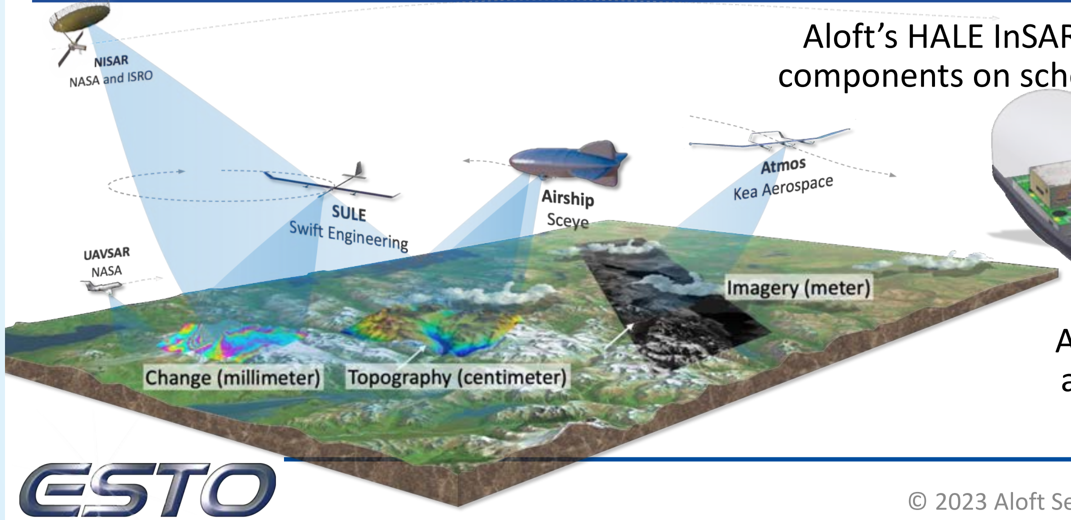
Project summaries

Aloft IIP Project Summary

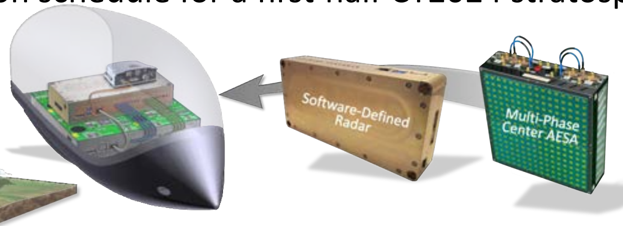
ALOFT SENSING

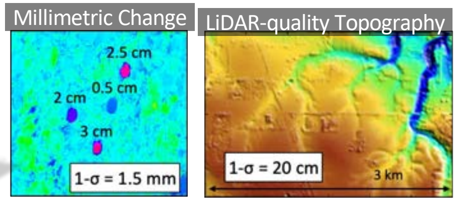
High Altitude, Long Endurance (HALE) InSAR for Continual and Precise Measurement of Earth's Changing Surface

- Solar-powered HALE aircraft and airships offer **affordable persistent regional access**.
  - Potential to capture the high-frequency dynamics of critical geophysical processes
- Aloft is applying novel algorithms & state-of-the-art electronics to **reduce the SWaP of InSAR** instrumentation and enable integration onto smaller and more affordable HALE platforms.
- Aloft is refining these algorithms to **overcome the challenges** associated with HALE operations: relatively slow velocities, often irregular trajectories, and coarse navigation control.
  - Aloft positioning and timing techniques ("AloftPNT") maintain sensor coherence over long collection times and wide spatial baselines
- Aloft's HALE InSAR has the potential to **improve revisit times** from weekly to sub-hourly (a 100x benefit), while also providing **ultra-precise sensitivity over broad-areas,** for a new level of regional presence and data accessibility.



Aloft's HALE InSAR system is currently in development, with key technology components on schedule for a first-half CY2024 stratospheric demonstration.





Aloft stratospheric demonstrations will show **mm-level deformation** and **cm-level topographic maps** at a **high repeat rate**, achieving the requirements of many key SDC and STV science objectives.

ESTO Earth Science Technology Office

Contact: info@aloftsensing.com

STV

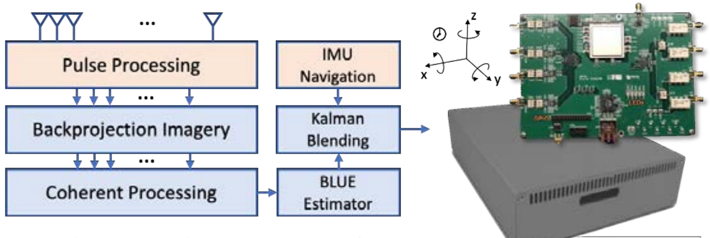
Project summaries

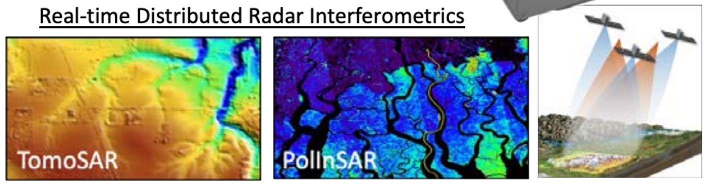
Aloft DSI Project: Embedded PNT Module For Distributed Radar Sensing

ALOFT SENSING

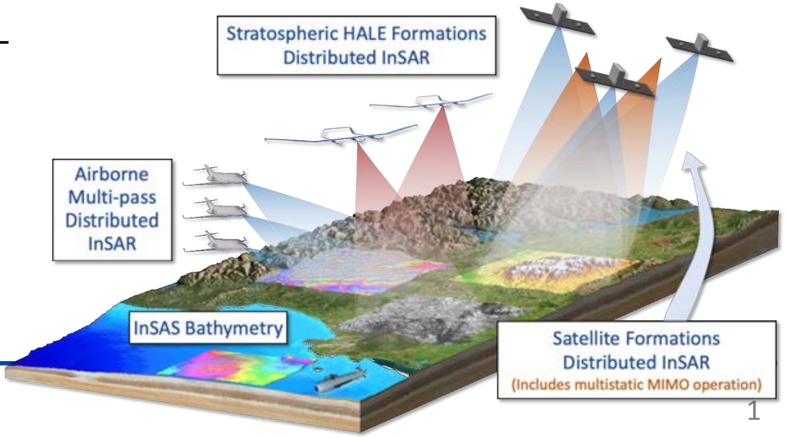
A Self-contained Positioning, Navigation, and Timing (PNT) Solution that Enables High-Resolution and Low-Latency Multi-Baseline Observations

- Aloft's patent-pending radar-based PNT (Positioning, Navigation, and Timing) technique provides **micron-level positioning, milli-degree orientation, picosecond timing** ("AloftPNT").
- This high level of precision is required for **coherent alignment of complex radar imagery** across distributed sensors to realize emerging techniques like multi-baseline polarimetric InSAR (PolInSAR) and tomographic SAR (TomoSAR) and achieve accurate 3-D volumetric reconstructions of surface vegetation and other structures.
- Under our DSI program, Aloft is developing, implementing, and testing a **prototype PNT module** that delivers high-precision PNT solutions in real-time.
- The resulting custom-built digital hardware, combined with efficiently embedded innovative algorithms, enables distributed interferometric radar formations to support new STV science investigations and provide **low-latency, high-resolution, high-accuracy** products.





Portable hardware module with embedded software/firmware to enable distributed radar STV measurements via AloftPNT.



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Radar Technology Gaps

- Polarimetric ”4D” SAR measurement sensitivities with respect to science disciplines and applications
  - New methodologies for application-specific processing algorithms
- Formation flying technology needs
  - Cross-platform synchronization
  - Cross-platform calibration
  - Metrology: measurement accuracy and knowledge
- Low data latency and persistent/short repeat observation are game-changing capabilities
  - Onboard processing
  - Long endurance airborne platforms
- Suborbital radar technologies
  - Formation flying
  - Multi-squint (angle) observation
  - Small & lightweight electronics
  - Continuous observation (lightweight, lower power, large onboard data storage, high-rate downlink, station keeping, smart sensing)

Technology Breakouts (Radar, Lidar, Stereoimaging, OSSEs, Platforms, Architecture)

- Measurement needs
- Current capabilities
- Emerging capabilities
- Identify measurement/technology gaps
- Strengths and weakness of approaches
- Advancements needed to achieve STV

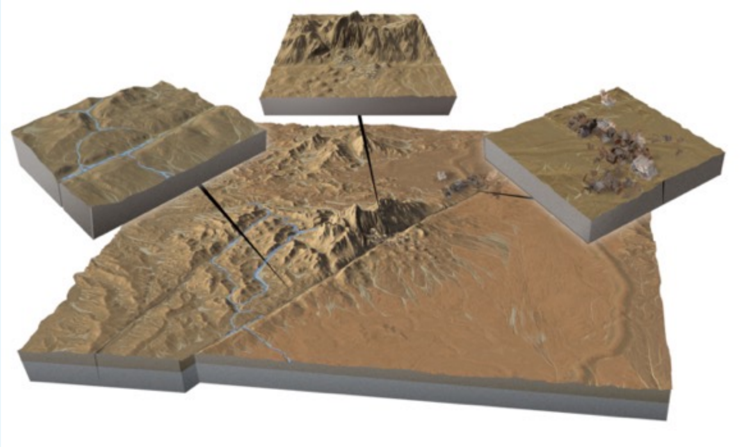
Mapping Stakeholder Needs to Radar Requirements

- What kind of spatial/temporal requirements do stakeholders want?
- What would be game-changing for your specific application, enabling entirely new possibilities?
- What kind of data latency do you require?
- What is your wish list beyond current capabilities?
- What kind of product (level) would be most useful to you?

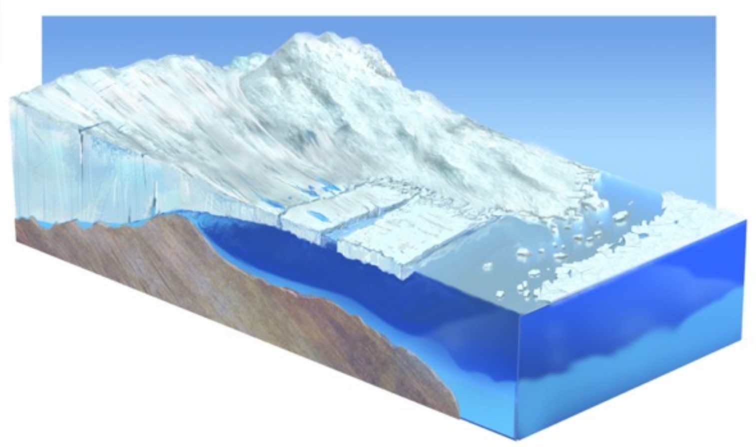
Backup

STV Science and Applications Measurements

Bare-surface Topography



Ice Topography



Vegetation Structure

Shallow-water Bathymetry