Updates on JPL's Tomographic Radar Experiment (TREx)

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Jet Propulsion Laboratory, California Institute of Technology

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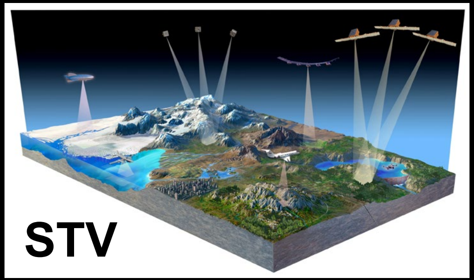
Initiative: Multi-static Radar Sensing



SDC

- The US National Academies of Sciences, Engineering and Medicine (NASEM) 2017 Earth Science Decadal Survey identified the designated and target observables **Surface Deformation and Change (SDC)** and the **Surface Topography and Vegetation (STV)**, respectively.
- Multistatic distributed radar systems have been identified as a key technology that can enable measurements required by the SDC and STV observables
- A critical component of distributed radar systems is the timing and synchronization of each platform. Typical system requirements depend on radar frequency and the application
- Below are tables of the STV measurement requirements and derived synchronization

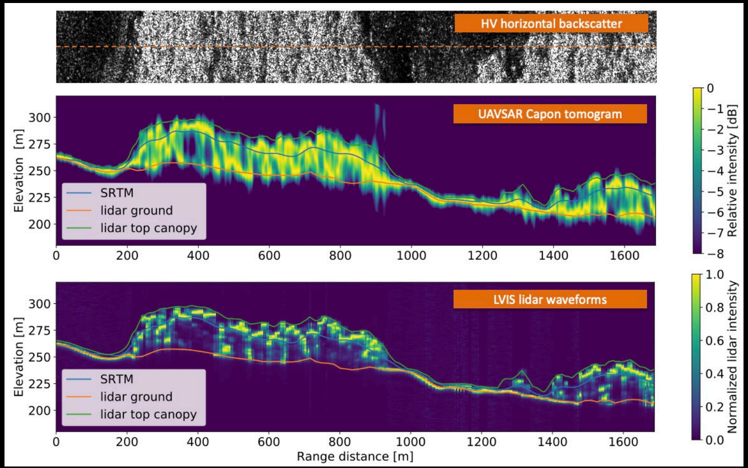
TABLE 3-2. Summary of preliminary measurement needs to accomplish STV science and applications objectives.

PARAMETER		ASPIRATIONAL			THRESHOLD		
		Median Need (rounded)	Most Stringent Need	Most Stringent Discipline	Median Need (rounded)	Most Stringent Need	Most Stringent Discipline
Coverage Area of Interest	%	90	95	C, H	55	90	C
Latency	Days	5	0.5	SE	60	1	SE
Duration	Years	9	10	SE, C, A	3	3	SE, V, C, CP
Repeat Frequency	Months	0.1	0.03	SE, A	3	0.2	SE
Horizontal Resolution	m	1	1	SE, C, H, A	20	3	SE
Vertical Accuracy	m	0.2	0.03	SE, C, H	0.5	0.1	C
Vegetation Vertical Resolution	m	1	0.5	H, A	2	0.2	CP
Bathymetry Max Depth	m	25	30	C, CP	10	10	SE, C, CP
Geolocation Accuracy	m	1	1.0	SE, V, H, A	5	3	SE, V
Rate of Change Accuracy	cm/y	5	1	SE, C, A	35	1	SE

TREx Synchronization Req.

Parameter	Error Allocation -Native units-	Error Allocation -Range Equiv.-
Total Relative Error	$\lambda/21$	1.12 cm
- Timing	35 ps	1.05 cm
- Frequency	($f_0 10^{-13}$ @ 5s)	0.02 cm
- Positioning	0.4 cm	0.4 cm

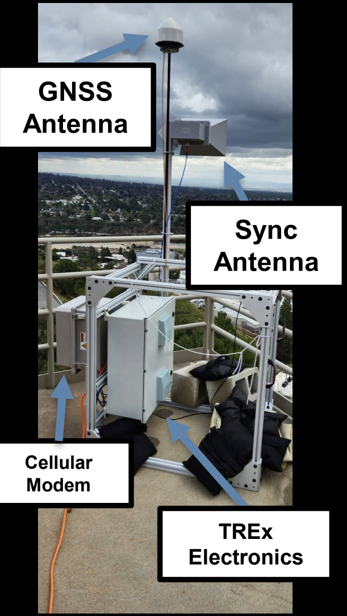
Tomographic Radar Experiment (TREx)



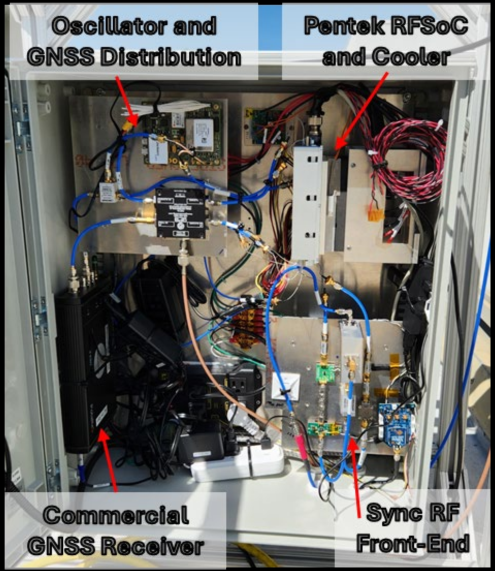
- **Goals of TREx**
  - Develop a distributed multi-static radar that can meet the needs of STV (3D-vegetation mapping) and SDC (3D-deformation vectors). Multi-static observations provide additional spatial information about the scene (2D image -> 3D volume).
  - Using GNSS and a RF cross-link, develop hardware to synchronize position, timing, and frequency for multi-static distributed radar.
  - Augment UAVSAR and AirSAR-NG to operate together as a distributed radar.
  - Collaborate with DLR on a synchronization method for joint multi-static radar experiments.

Test Stand Development

- A set of test stands have been developed at JPL for testing the GNSS and timing/phase synchronization hardware and algorithms

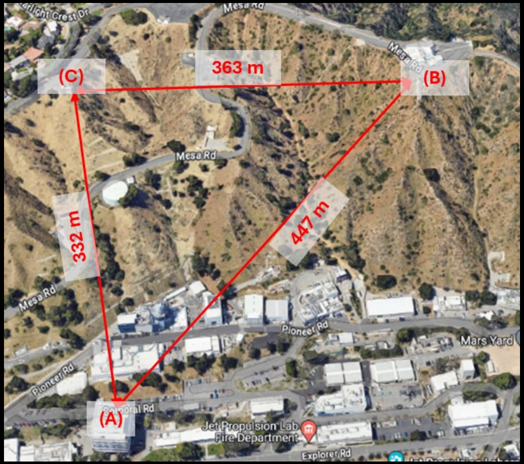


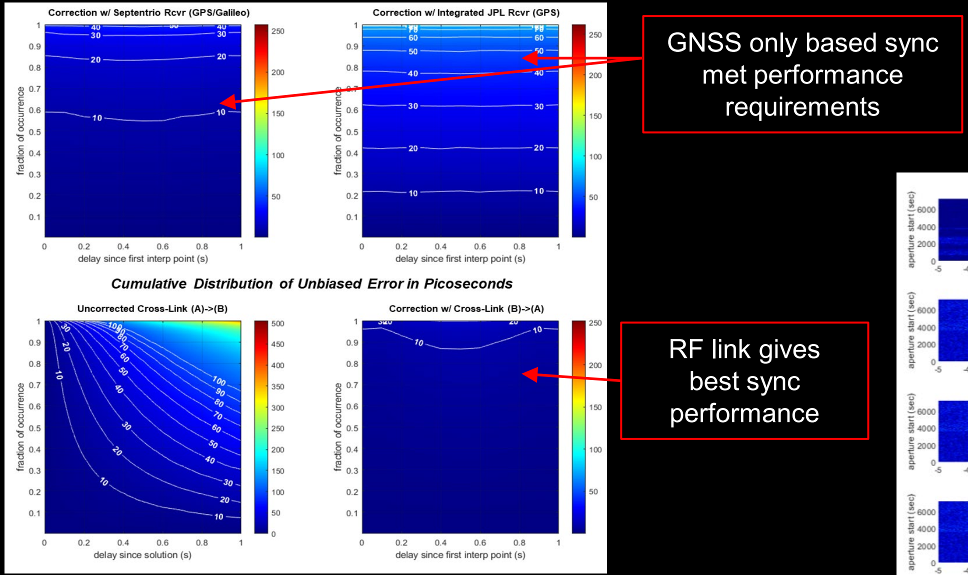
- Each test stand contains an electronics box which includes:
  - RFSoC-based radar system, signal conditioning, a commercial GNSS receiver, and GNSS distribution
- Attached cellular modem allows for remote operations during ground testing
- Total of 3 test stands were developed for the stationary testing
- 4th unit has also been developed, which is used as a mobile target (mounted on a pushcart or in a vehicle)



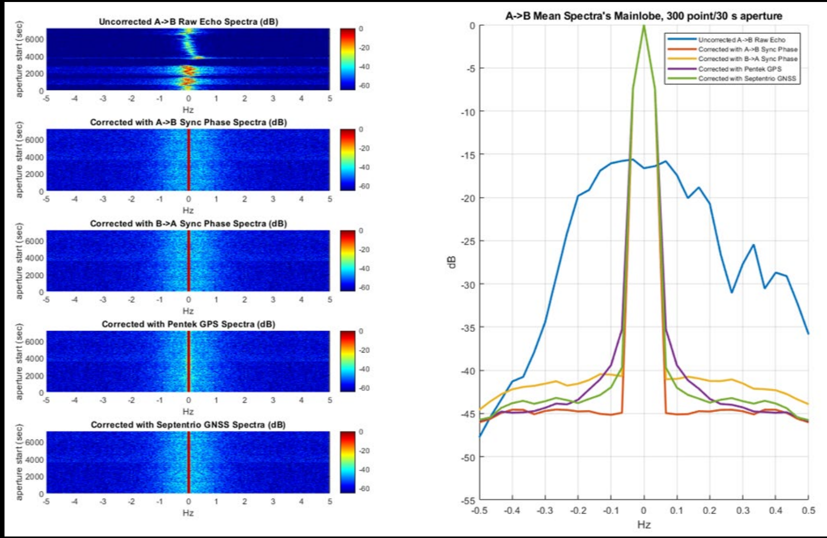
First Experiments: Static Platforms

- 3 static test stands were deployed across JPL (~330 – 450m distance)
- Each platform transmits and receives each other's signals
- Synchronization algorithms using both GNSS and RF cross-link demonstrates ability to correct phase errors





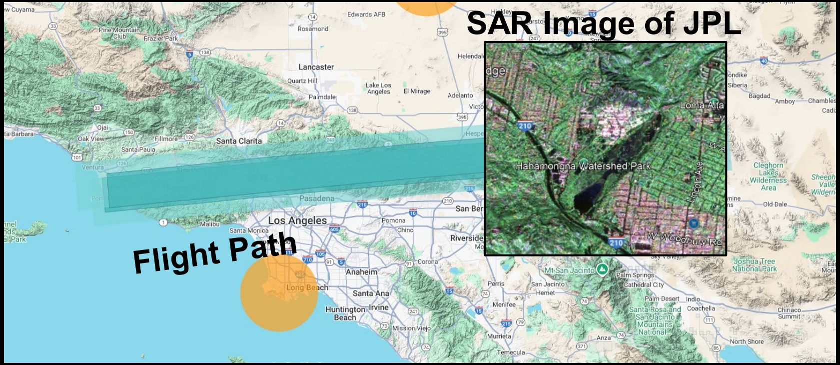
Above: Cumulative distribution as a function of time relative to the sync solution is evaluated using all data for a 2-hour test. The contours show the relative fraction of samples that are within a relative timing error level.

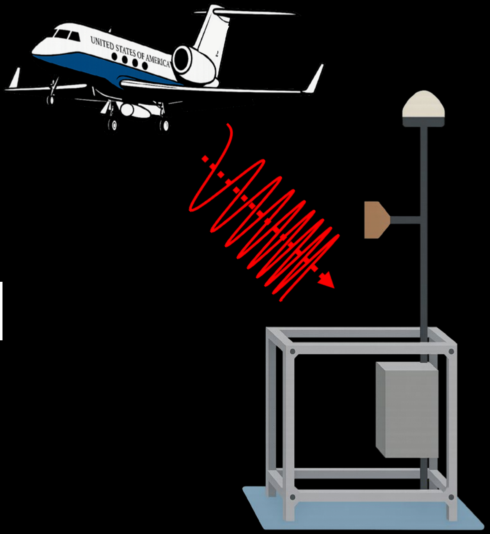


Right: Example Doppler spectra after 30s integration, analogous to SAR azimuth processing

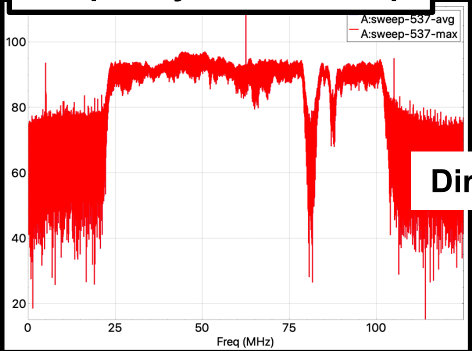
Experiments with UAVSAR

- UAVSAR conducted a flight campaign over the Eaton burn scar (adjacent to JPL) on Feb. 26
- TREx test stands were configured to operate in a “listen only” mode
- This experiment examines the capability to synchronize with a non-cooperative transmitter
  - This is a similar situation to operating a coflier with NISAR as transmitter
  - Under-flights of UAVSAR and NISAR also a possibility

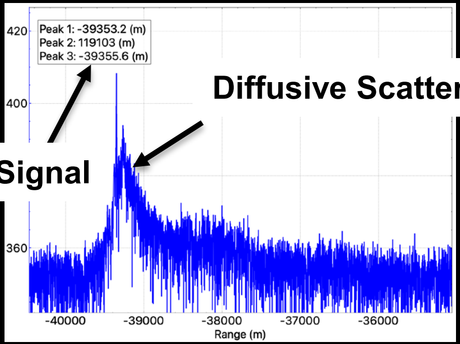




Frequency Domain Chirp

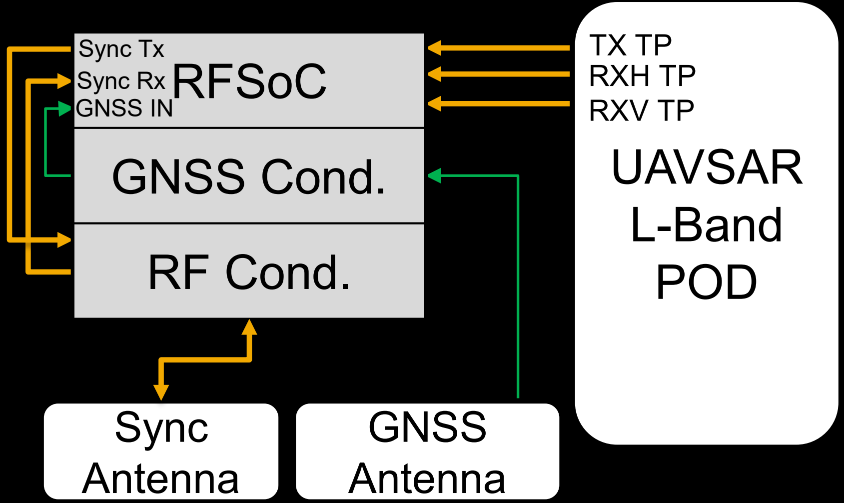


Range Compression



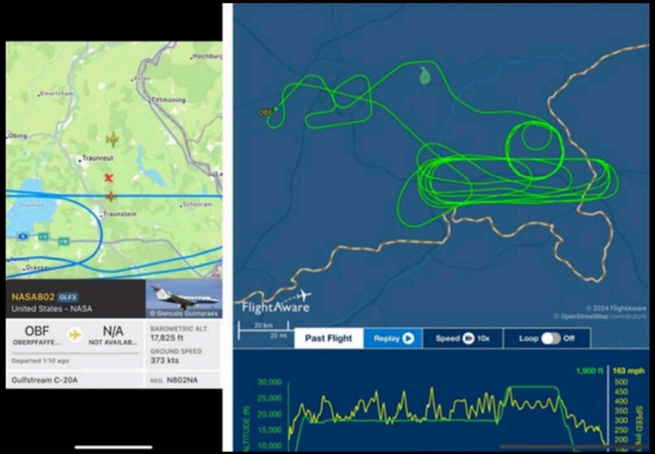
Future Roadmap: UAVSAR Integration

- For future experiments, TREx platforms will be both on the ground and in-cabin for sync and UAVSAR sampling
- We will mount a sync antenna on the aircraft and utilize UAVSAR engineering flights to test synchronization between static platforms and airborne platform
- We are also currently working on an out-of-band synchronization. Radar operates at L-band and RF synch link operates at S-band
- Hardware is being integrated for this case both on UAVSAR and in the TREx test stands



TREx's Future Roadmap

- In July 2024, JPL's UAVSAR and DLR's F-SAR conducted bistatic experiments where UAVSAR transmitted and both platforms received
- TREx is implementing a synchronization system on UAVSAR and AirSAR-NG for bistatic and multi-static experiments
  - When NISAR launches, we're planning to conduct multi-static tests using NISAR as a transmitter
- JPL is collaborating with DLR to define and implement synchronization scheme to support joint multi-static fight campaigns
  - JPL would like to develop an open standard to better support future collaborations with other institutions and agencies
- JPL is committed to continue co-operative flight campaigns with DLR to demonstrate multi-static flights
- TREx is developing distributed radar synchronization hardware and demonstrating multi-static measurements as a path towards multi-static spaceborne missions
  - Our near-term goal is to support the co-flier concepts being developed using NISAR or ROSE-L as transmitters



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