DARTS

Distributed Aperture Radar Tomographic Sensors

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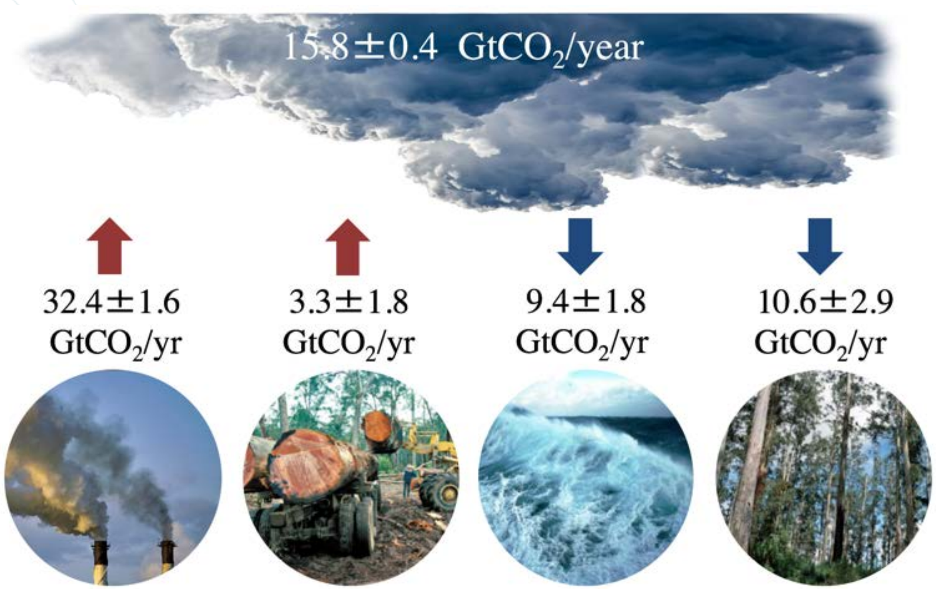
Program: IIP-19

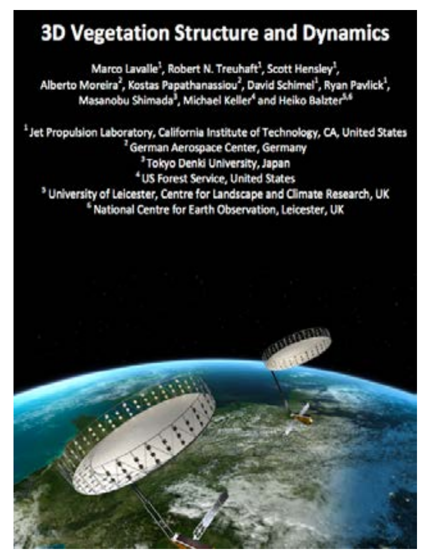
Jet Propulsion Laboratory, California Institute of Technology

Science question being addressed

- Large uncertainty in atmospheric carbon dioxide changes due to poor knowledge of spatiotemporal patterns of carbon sources and sinks
- Current approaches fail due to limited sampling, coverage, or AGB range applicability
- 2017-2027 Decadal Survey recommended global mapping of surface topography and 3D vegetation structure as high-priority “incubator measurement”
- How do we measure vegetation 3D structure (global, 3-5m vert., 50m horiz, 5+ years) to quantify range and accuracy of AGB and AGB change globally?



JPL-led Decadal Survey RFI#2



3D Vegetation Structure and Dynamics

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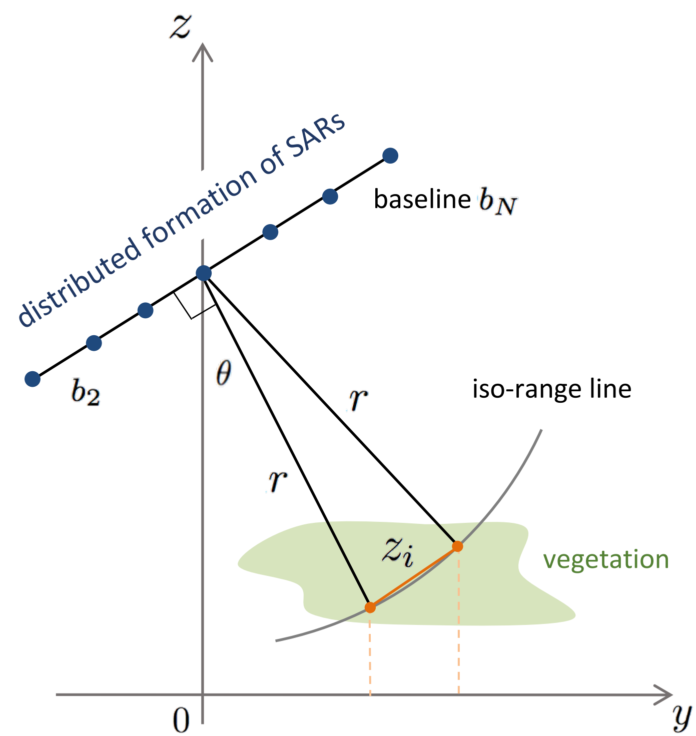
Solution: TomoSAR with DARTS

- DARTS = distributed formation of SAR satellites enabling TomoSAR technique
- In single-image SAR, echoes from scatterers at same range *r* are mixed
- In TomoSAR, signals *s* received at distinct orbital locations carry spatial harmonics proportional to height *z* of the scatterers
- Phase history is used to recover the height of the scatterers via spectral estimators (e.g. Fourier, Capon)



$$\mathbf{s}(n) = \sum_{m=1}^{N_s} \sqrt{\sigma_m}\mathbf{x}_m(n) \odot \mathbf{a}(z_m) + \mathbf{g}(n) \quad n = 1, \ldots, N_l$$

$$P_F(z_m) = \frac{\mathbf{a}^\dagger(z_m)\widehat{\mathbf{R}}_s\,\mathbf{a}(z_m)}{N^2}$$

3D structure

$$\widehat{\mathbf{R}}_s = \frac{1}{N_l}\sum_{n=1}^{N_l} \mathbf{s}(n)\mathbf{s}^\dagger(n)$$

covariance matrix

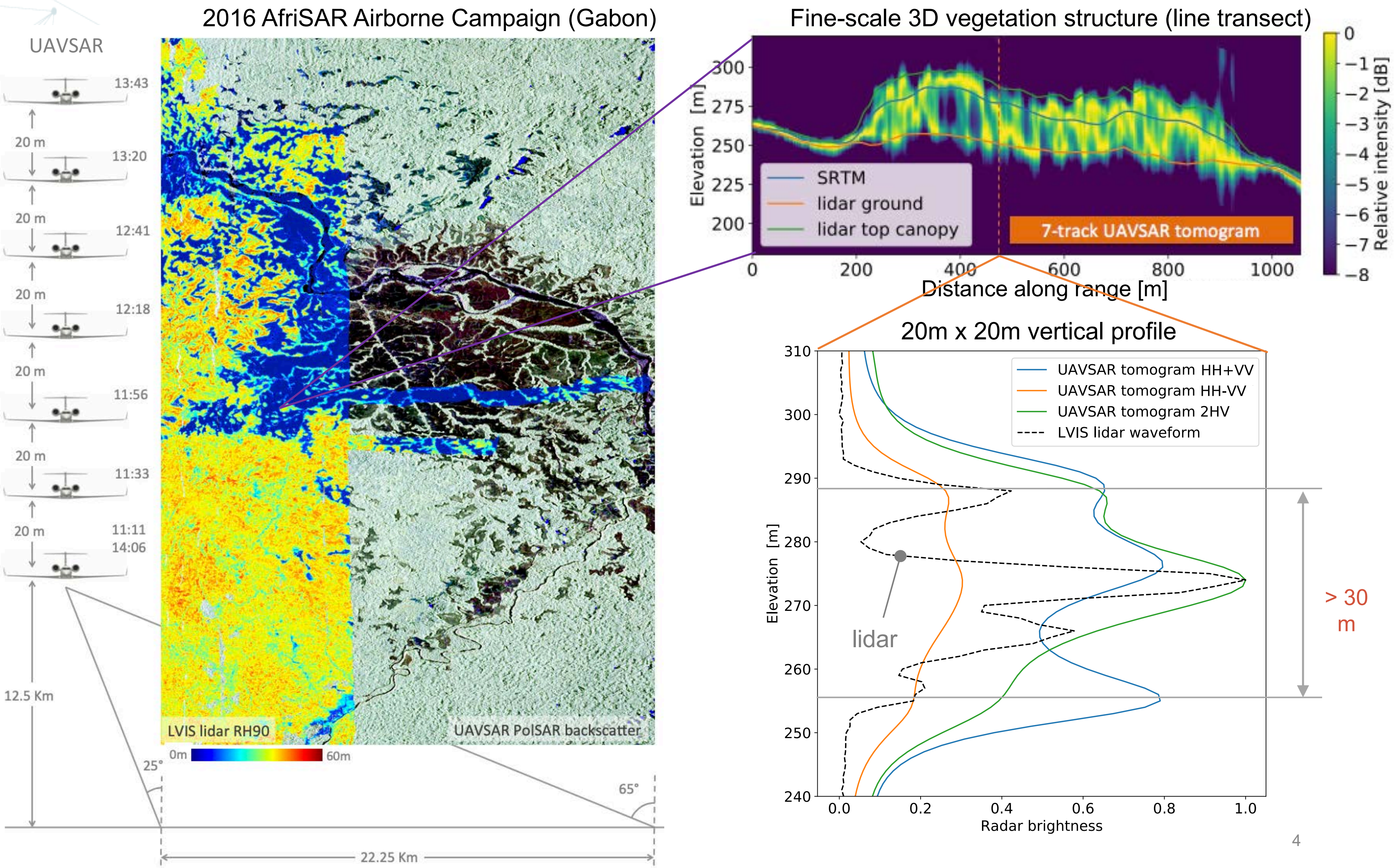
$$\mathbf{a}(\omega) = \begin{pmatrix} 1 \\ e^{j\omega b_2} \\ \vdots \\ e^{j\omega b_N} \end{pmatrix}$$

steering vector

$$\omega(z) = \frac{4\pi z_i}{\lambda r} = \frac{4\pi z}{\lambda r \sin\theta}$$

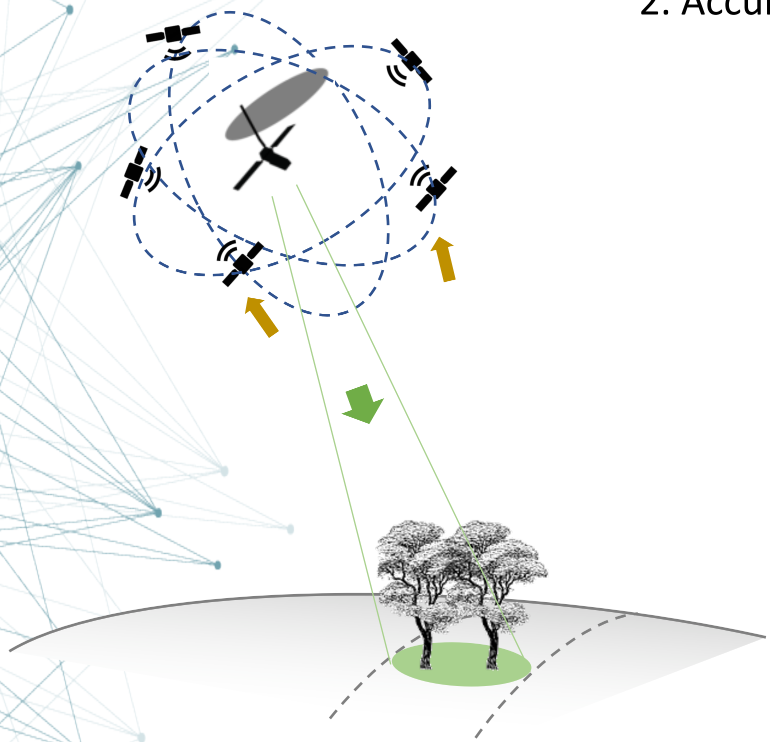
spatial frequency

TomoSAR with JPL airborne experiment



DARTS | Technology challenges

1. Optimal observation geometry configuration with realistic spacecraft orbits



2. Accurate distributed relative cm-level localization

3. Mutual signal phase synchronization

4. Small-Sat compatible, light-weight deployable antenna and compact radar electronics

5. Integrated system performance encompassing system and science requirements

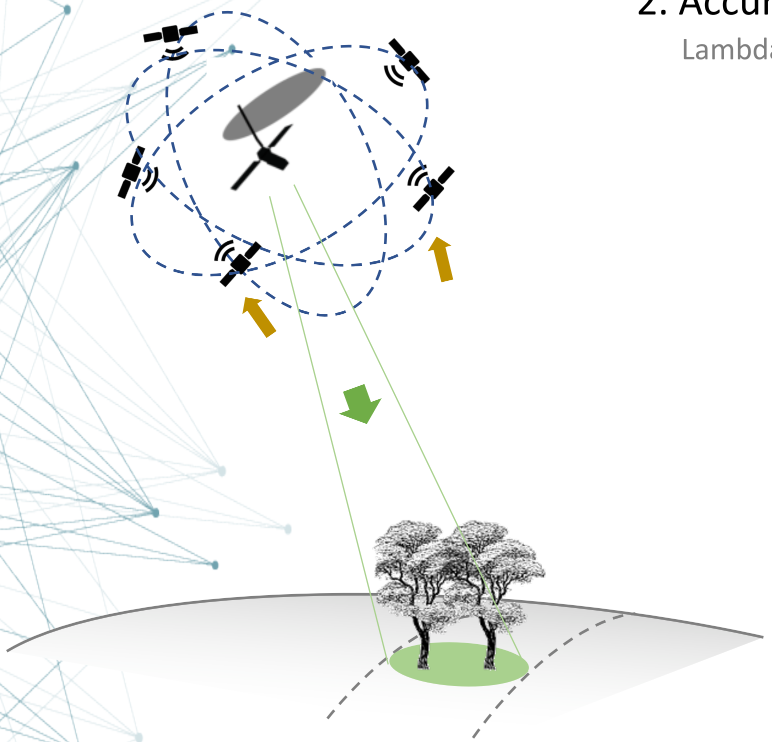
6. End-to-end SAR processing applied to multi-static tomographic validation data

DARTS will deliver a "solution" with documented performance for each of the points 1-6 above leading to a feasible mission concept for TomoSAR

DARTS | Technology challenges

1. Optimal observation geometry configuration with realistic spacecraft orbits

Single transmitter and 5-10 receivers (or all tx/rx). Passive relative orbits described by 5 parameters adaptable to veg. structure



2. Accurate distributed relative cm-level localization

Lambda/20. Explore GPS-only and N-body multi-lateration algorithm

3. Mutual signal phase synchronization

Inter-sat comm. with estimation of time of flight and phase errors

4. Small-Sat compatible, light-weight deployable antenna and compact radar electronics

L-band 7-panel patch array antenna. Explore membrane antennas

5. Integrated system performance encompassing system and science requirements

Trade study tool with inputs from STV study team's SATM

6. End-to-end SAR processing applied to multi-static tomographic validation data

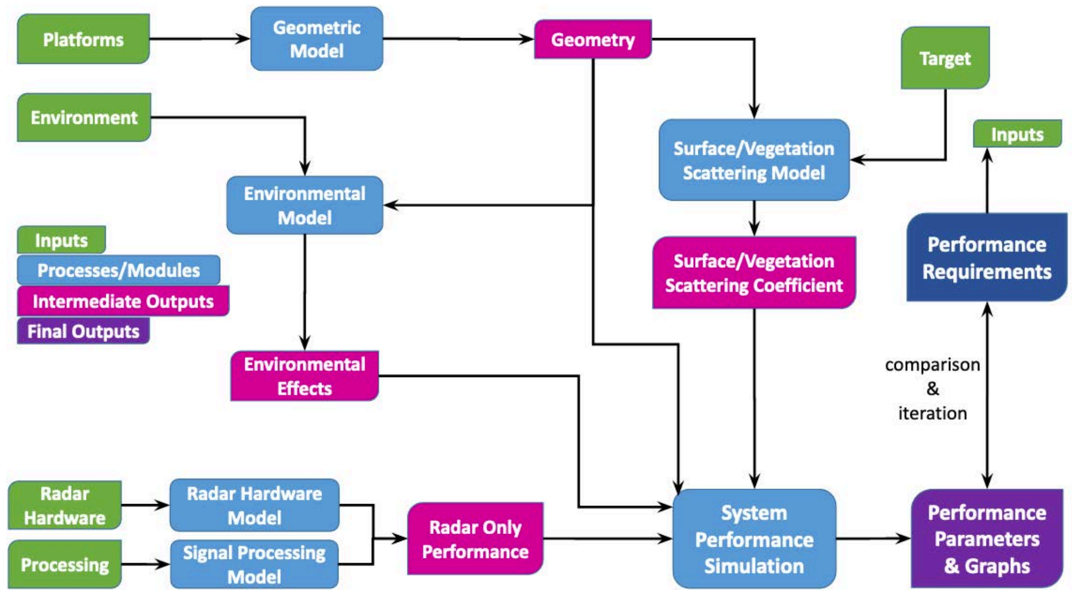
Static and dynamic experiments using COTS hardware and Caltech drones

DARTS will deliver a "solution" with documented performance for each of the points 1-6 above leading to a feasible mission concept for TomoSAR

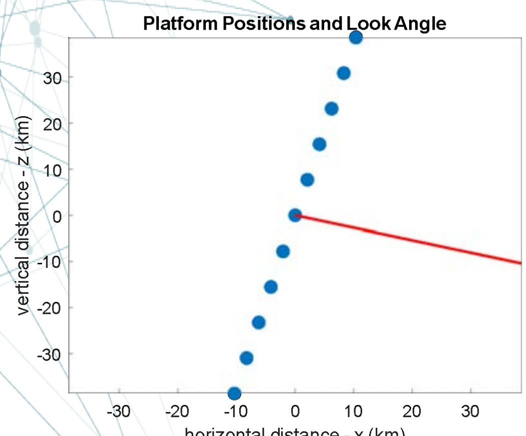
DARTS | Example of trade study

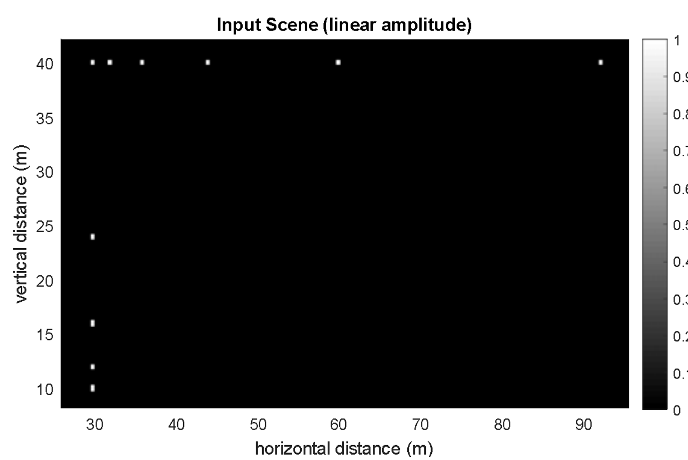
Time-varying orbit solutions

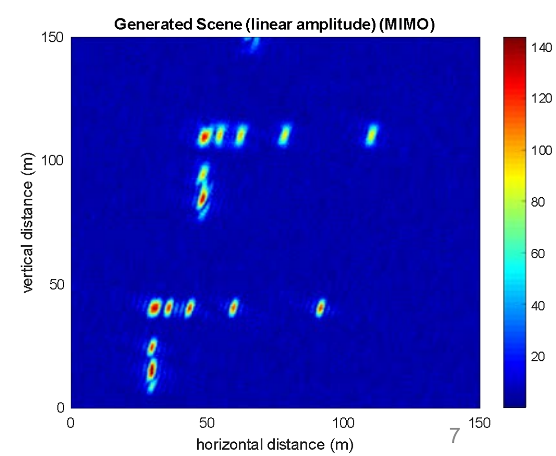
Sync and localization error models



STV Study Team SATM



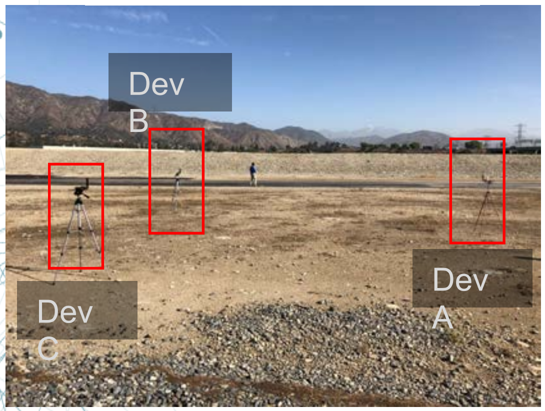




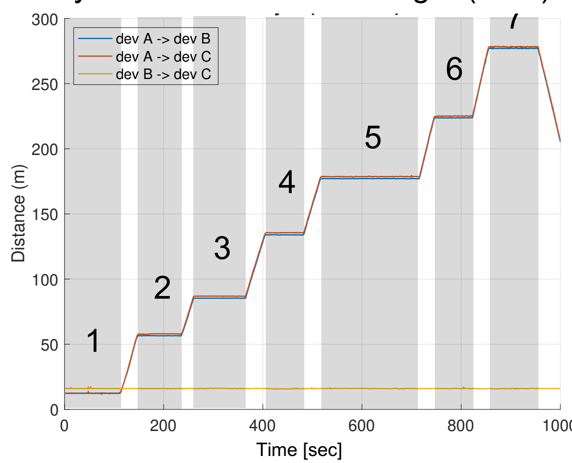
DARTS | Algorithms and concept validation

Ground experiment: Sensor *A* moves away from fixed *B, C* in 50m steps, 2.4 GHz test, interference from RC airplanes

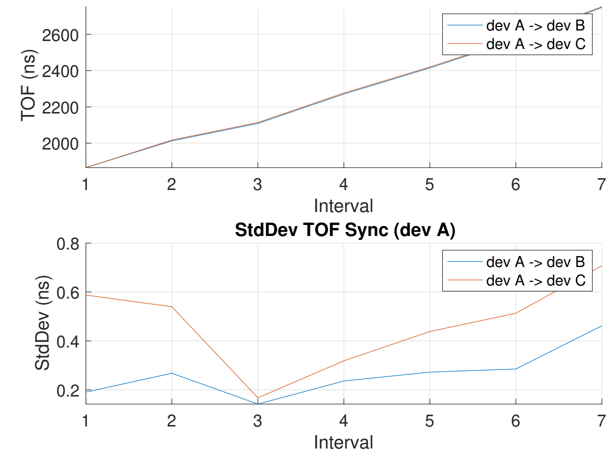
Synchronized TOF distance



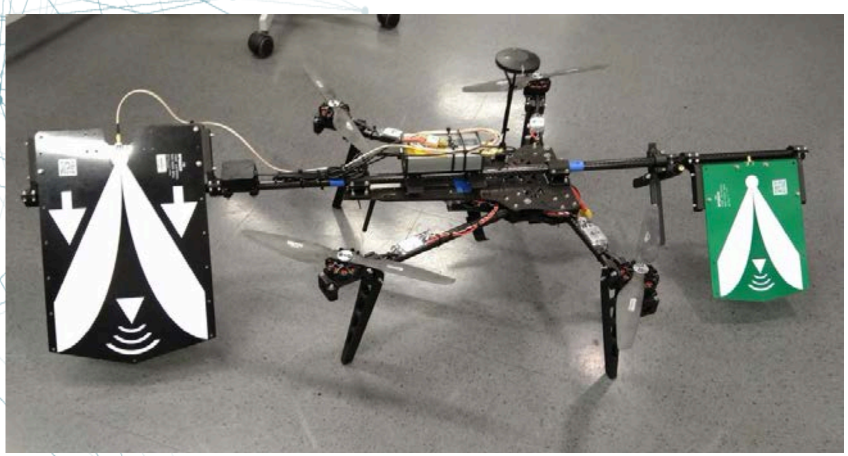
Synchronized Time-Of-Flight (TOF)

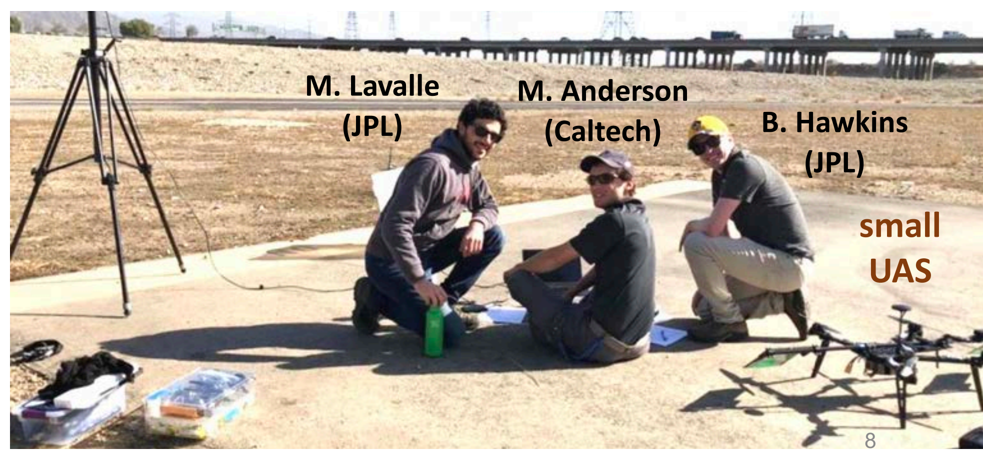


Moving sensor Statistics



sUASs experiment: Generate tomograms after sync and location for varying vegetation types and flying geometries





DARTS | Plan for Year 1

- TASK 1 – sync and localization
  Develop synchronization and localization algorithms and formulate error models to be incorporated into trade study. Start implementation on Xilinx RFSoC
- TASK 2 – orbits
  Design orbits for TomoSAR constellation with desired baseline distribution for varying geographic locations and vegetation heights
- TASK 3 – sUASs
  Mount COTS radar(s) on one or two drones and test single-image radar processing. Test preliminary synchronization/location algorithms
- TASK 4 – trade study
  Develop and conduct trade study with multi-static radar geometry module and realistic orbits coupled with synchronization/localization models
- TASK 5 – antenna
  Design 7-panel foldable patch array antenna and analyze electrical/mechanical performance. Study changes in design and performance for receive-only antennas

Summary

- DARTS (PI: Marco Lavalle) is a 3-year IIP project started in April 2020 to mature and demonstrate technologies that enable global vegetation structure and surface topography measurements using TomoSAR
- DARTS will deliver a viable mission concept for TomoSAR with demonstrated performance of the enabling technologies
- Technologies include phase synchronization, platform localization, SAR formation flying geometry, and miniaturized spaceborne radars
- Impact for Decadal Survey's Surface Topography and Vegetation (STV) incubator measurement
- First results of tomographic performance with simplified models and flying geometries expected by Q1 FY21