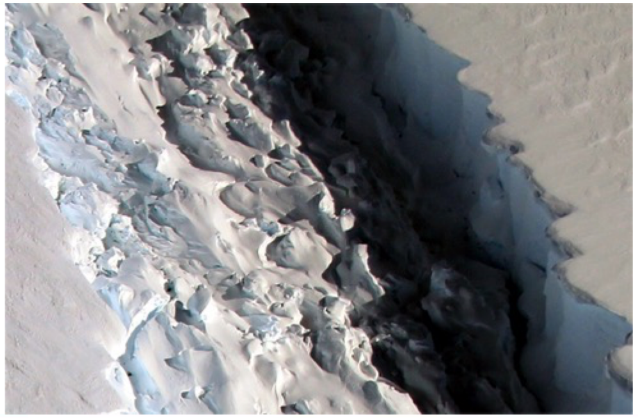
SCIENCE






Surface Deformation and Change Architecture Process

Stephen Horst[1], Katia Tymofyeyeva[1], Shadi Oveisgharan[1], Batuhan Osmanoglu[2]

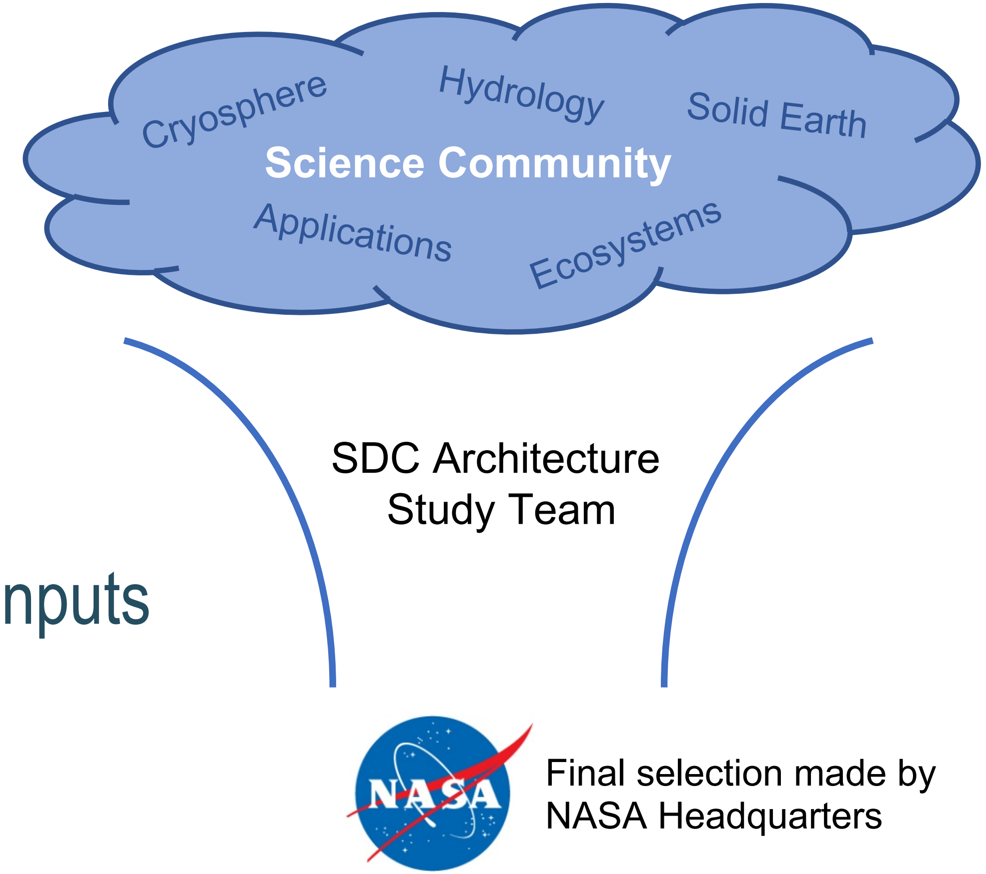
[1]Jet Propulsion Laboratory, California Institute of Technology
[2]NASA Goddard Spaceflight Center

May 2020

Designing NASA’s Next Generation SAR Mission Architecture

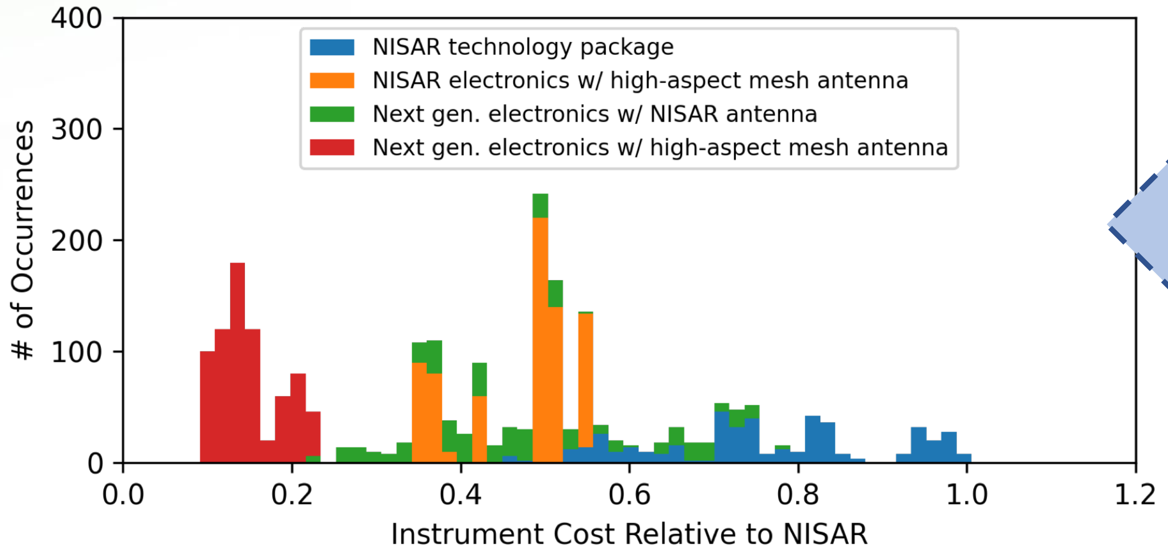
The 2018 Decadal Survey process has opened participation in mission development.

- Phase I: Brainstorming (2019-2021)
- Phase II: Down-selection (2021-2023)
- Make sure your voice is heard!
- Needs are collected through working group inputs

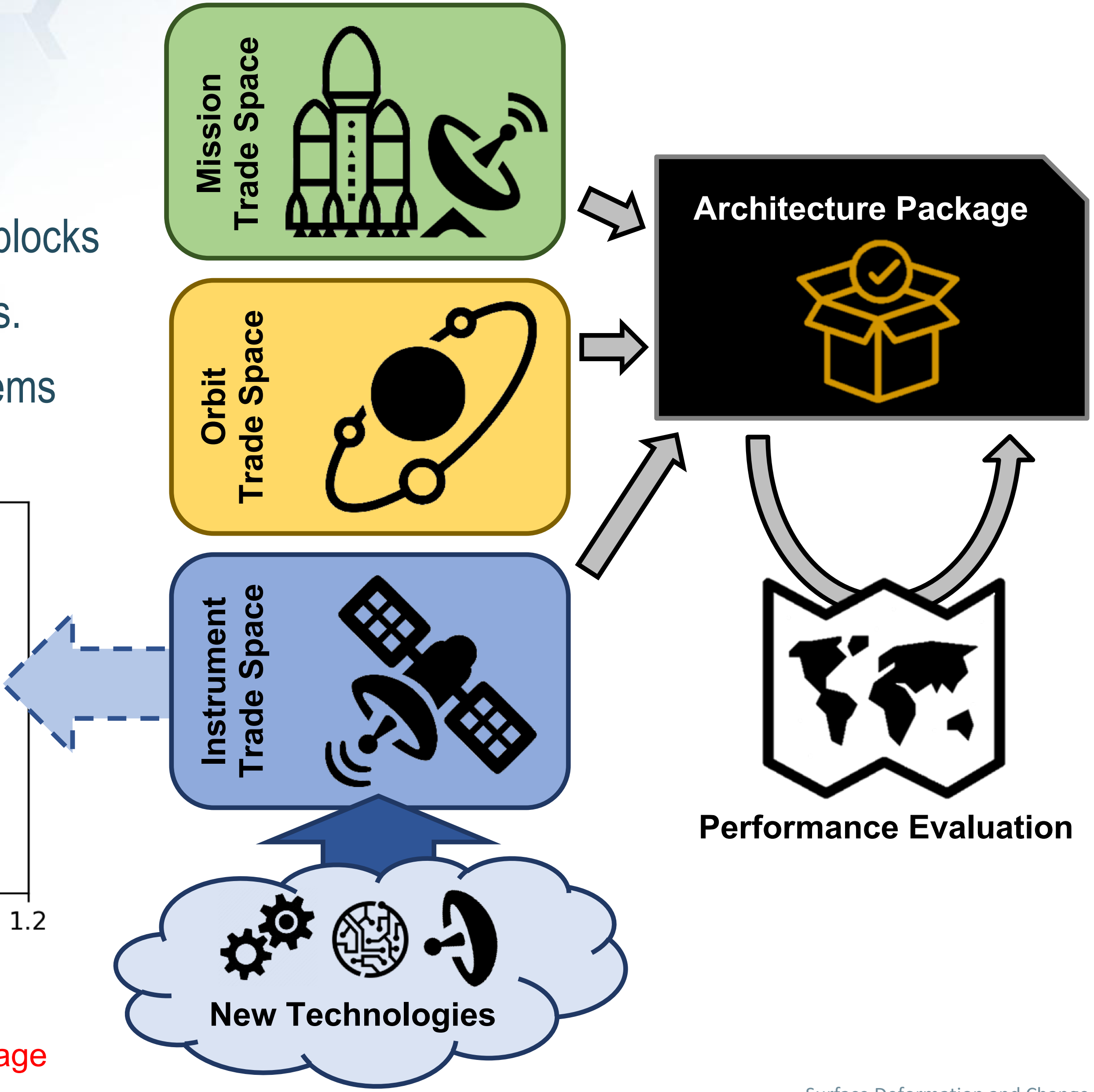


Brainstorming Approach

- Goal: Systematically evaluate all viable approaches
- “Trade spaces” represent possible mission building blocks
- Technology focus and investment on the instruments.
- Follow industry advancement for other mission systems



- Technology mix can drive down cost per instrument
- Does not reduce mission cost for systematic global coverage



SDC Trade Space

- Trade space made up of all "building block" elements that could contribute to SDC goals: performance or programmatic
- Trade space elements that have continuous possible ranges broken into broad categorizations
- Broken into separate "Instrument", "Orbital", and "Architecture" spaces to aid in compiling possible architectures (see next slide)

Instrument Building Blocks:

- Frequency Band: L-band, S-band, C-band, X-band
- Orbital Duty Cycle: 15%, 50%
- Scanning Mode: Stripmap, SweepSAR, ScanSAR
- Elevation Beamwidth: 2 deg, 3 deg, 4 deg, 6 deg, 12 deg (proxy for swath width)
- Polarization: Single-pol, Dual-pol, Quad-pol
- Single Look Resolution: 5 m, 10 m, 15 m
- Noise-Equivalent Sigma$_0$: < -15 dB, < -25 dB

Orbital Building Blocks:

- Repeat Period: 10 - 16 day
- Orbit Altitude: 450 - 750 km
- Inclination: 60 deg - Sun-sync
- Coverage Technique: Single, Equi-Spaced, Grouped

Architecture Building Blocks:

- Launch Vehicles: Small Lift, Medium Lift, Heavy Lift
- Launch Sequence: Phased, Simultaneous
- Flight Spares: Yes, No
- Mission Duration: 3 yrs, 5-7 yrs, 8+ yrs
- International Contribution: ISRO, ROSE-L, Sentinel, None
- Commercial Augmentation: Yes, No
- Multi-Squint Corrections: Yes, No
- Co-flyer Coordination: Yes, No
- Data Latency: < 4 hrs, < 1 day, < 1 week, None
- Downlink Options: X-band, Ka-band, Optical, TDRSS
- Coverage: Global, Selective
- Host Other Payloads: Yes, No

Evaluating Architectures

- Outputs of the brainstorming process become inputs to the down-selection process
- Need simple metrics that can be weighed across mission architectures

Architecture Package

- Trade Space Inputs
- Cost Estimates
- Engineering Estimates
- **Performance Estimates**
- Technology Assessments
- Risk Assessments

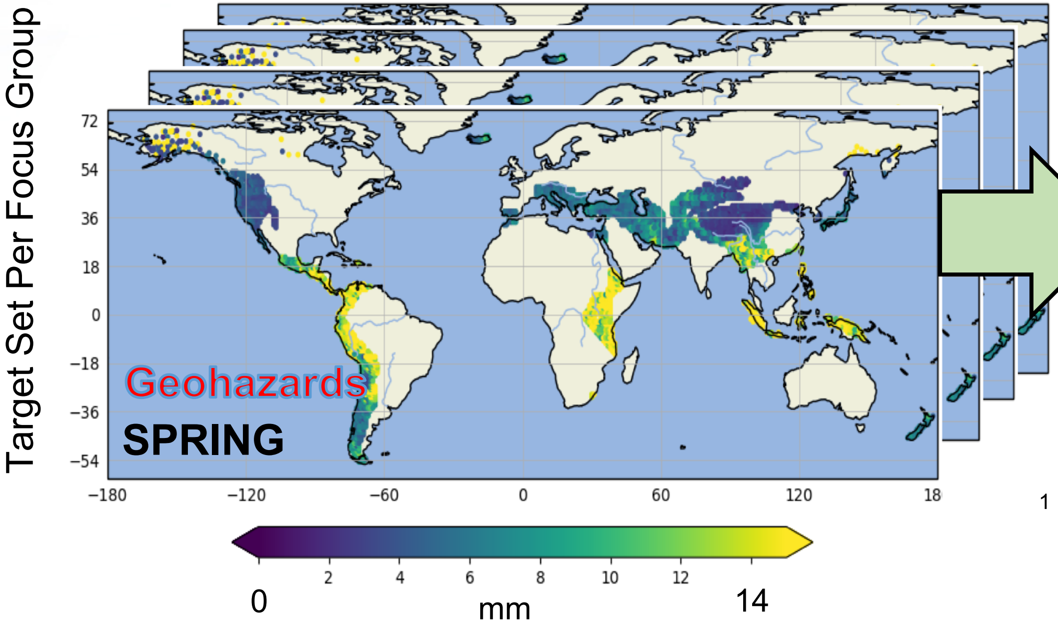
Metric	Cryosphere	Ecosystems	Geohazards	Solid Earth
Seasonal/yearly East-North-Up (ENU) and Line-of-Sight (LOS) displacement uncertainties[1]	X			X
Seasonal and yearly range/azimuth offset uncertainties[1]	X			
Number of viable data acquisitions seasonally	X		X	X
Percentage of targets observable during each season	X	X	X	X
Overall uncertainty of targets at the required coverage (70%)	X		X	X
Percentage of targets with deformation accuracy below the SATM requirement	X	X	X	X
Event-based[2] displacement and velocity uncertainties in ENU and LOS over a time period[1]			X	

[1] Per ground target over a given spatial scale
[2] "Events" can occur at different times of the year and last for varying amounts of time

Example Performance Evaluation Outputs

- Different sets of targets relate architecture performance to different scientific disciplines (shown below)
- Uncertainties from thousands of targets are condensed into summary statistics for each discipline
- Hydrology is a recently added focus group: need a set of targets representing areas of interest.
- **Methodology gives the ability to frame performance evaluation from the global to the local scale**

Geo-located Performance



Seasonal Statistics

Season	Coverage	DU[1] (mm)
WINTER	74.6%	10.0 (at 20km)
SPRING	80.9%	10.1
SUMMER	96.1%	13.2
FALL	94.2%	9.1

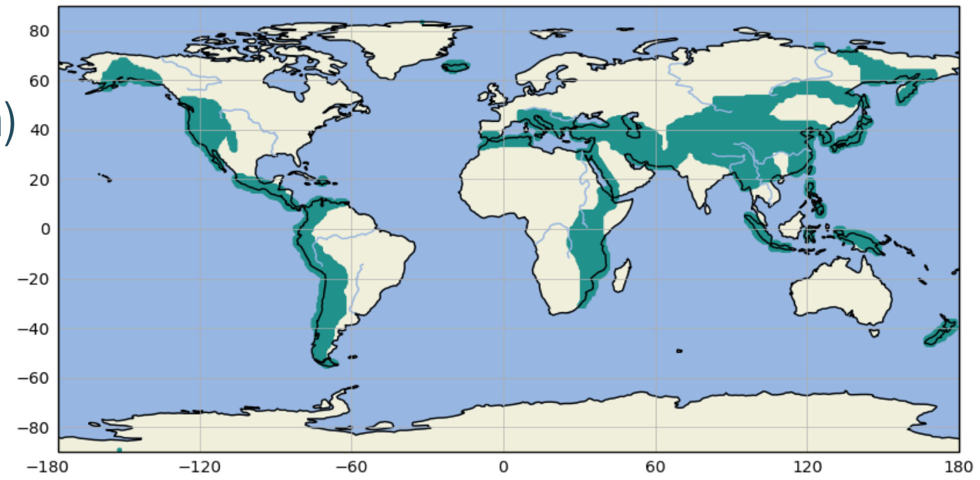
[1] Average line of sight displacement uncertainty

Summary Statistics

Category	Coverage	Uncert.
Solid Earth	83.1%	9.2 mm
Cryosphere	70.1%	10.1 mm
Geohazards	85.2%	9.1 mm
Biomass	…	…
Hydrology	…	…
Soil Moisture	…	…
…	…	…

Performance Tool Models

- The tool translates radar measurement errors into geophysical estimate errors for a specific architecture
  - Radar measurement errors include interferometric phase error or backscattered power error
  - Geophysical estimate errors include items such as vertical displacement error or biomass estimation error
- The tool takes a modular approach to geophysical estimates, requiring the following definitions:
  1. Geo-located regions of interest
  2. An algorithm for translating measurement errors to geophysical error
- The following models are currently planned:
  1. Deformation estimation error
  2. Biomass estimation error
  3. Biomass disturbance error (needs to be augmented for constellation)
  4. Soil moisture estimation error (under development via NISAR)
- Additional models are possible, but would require the time, staffing, and funding to implement



Point target location definition for the Geohazards evaluation

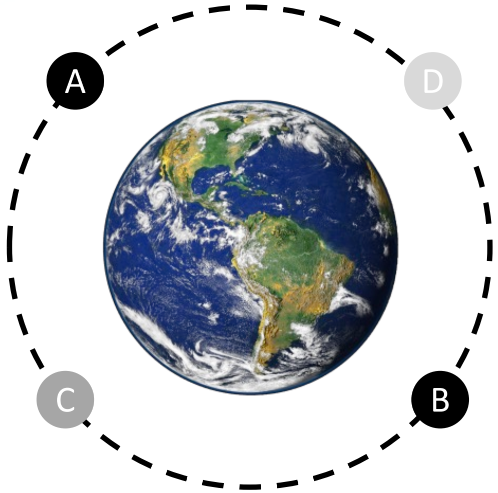
Architectures Currently Under Consideration

- Several classes of architectures under evaluation, each with a variety of implementations
- Each class offers advantages in different *capability* areas:
  - **Continuity**: Likelihood of extending the current program of record beyond NISAR with overlap
  - **Temporal Coverage**: Improving the time between interferometric repeat intervals
  - **Error Reduction**: Reducing the measurement uncertainty by real time estimates of tropospheric delay
  - **Look Diversity**: Improving deformation estimation in all 3 spatial dimensions to enable new science
  - **Radiometry**: The ability to produce useful radiometric data in addition to interferometric products
  - **Spatial Coverage**: The portion of the globe covered by the instrument in its repeat cycle

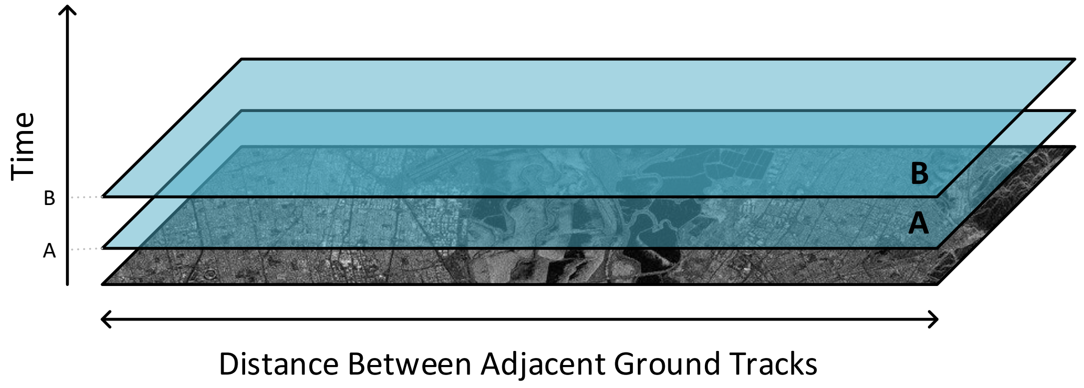
Flagship Fleet Architectures

Capability	Ranking
Continuity	
Coverage	
Error Reduction	
Look Diversity	

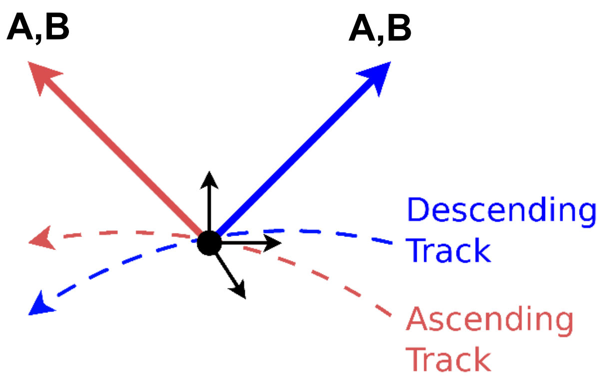
- Characterized by individual spacecraft each with global coverage capability
- Adding spacecraft to the constellation increases the global temporal sampling rate
- Works well as a basis for multi-national collaboration or spec-based acquisition plan
- Requires firm commitment to the measurement because costs for a flagship architecture are high.
- ROSE-L is an example of this architecture paradigm.



Orbital Plane Spacing



Ground Track Spacing

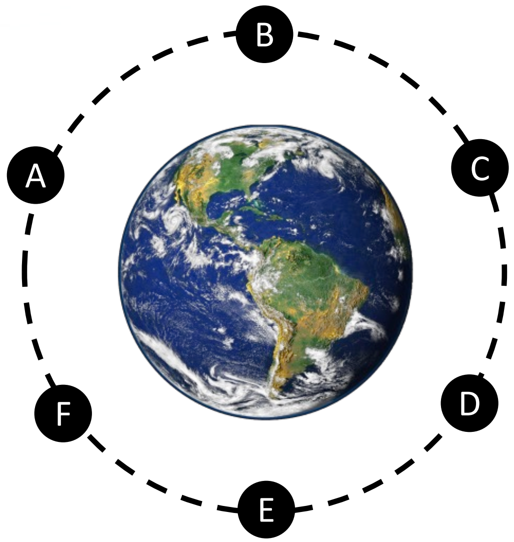


Point Target Look Diversity

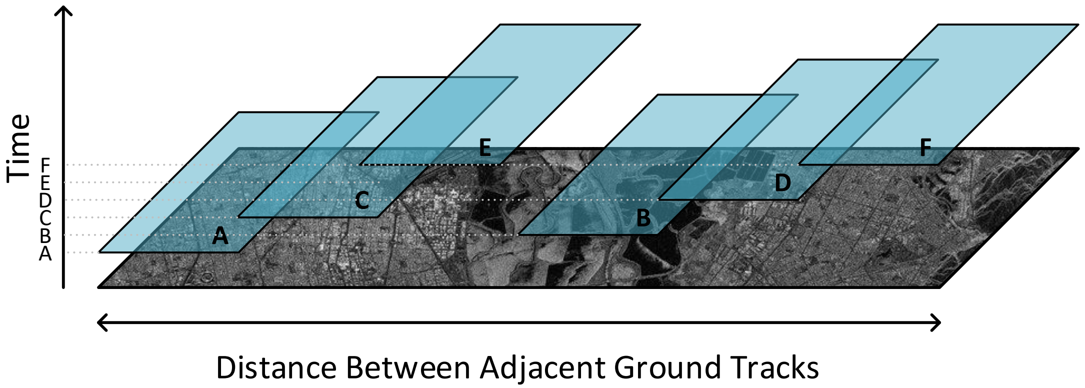
Distributed Repeat-Track Architectures

- N equally distributed smaller satellites that cover 1/N of the adjacent ground track swath
- Gets complete global coverage based on the orbital repeat period
- For urgent response needs, all satellites mechanically steered to the same look angle
- Decreases interferometric repeats by a factor of N over the desired sub-swath

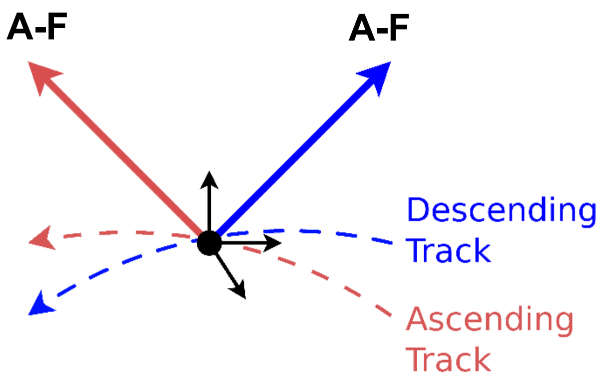
Capability	Ranking
Continuity	Green
Coverage	Green
Error Reduction	Red
Look Diversity	Yellow



Orbital Plane Spacing



Ground Track Spacing

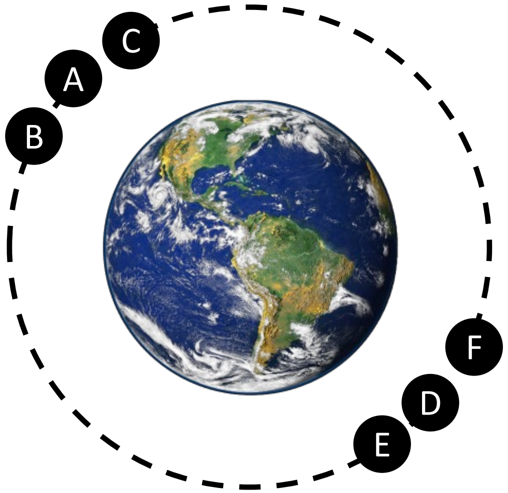


Point Target Look Diversity

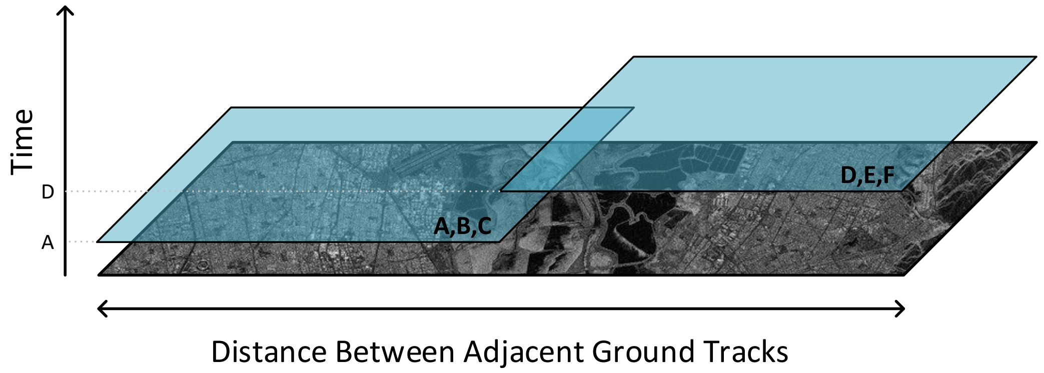
Multi-Squint Formation Architectures

- Forward and backward squinted satellites, surrounding a zero-Doppler satellite
- Multiple real-time look angles enable accurate removal of tropospheric delay
- Look diversity enables good estimation of all 3 spatial components
- Enables new science at the expense of coverage density
- Concept presented by Mark Simons at Living Planet Symposium 2019

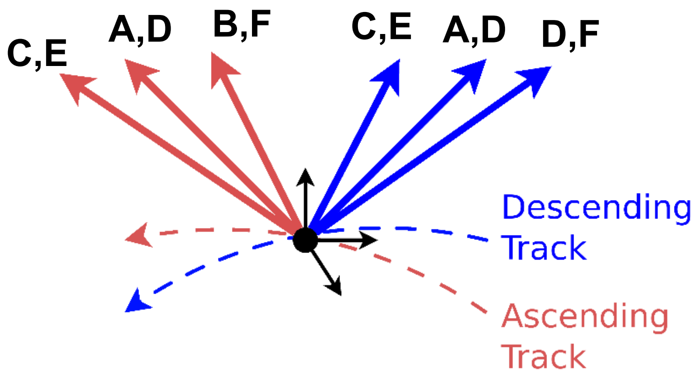
Capability	Ranking
Continuity	
Coverage	
Error Reduction	
Look Diversity	



Orbital Plane Spacing



Ground Track Spacing

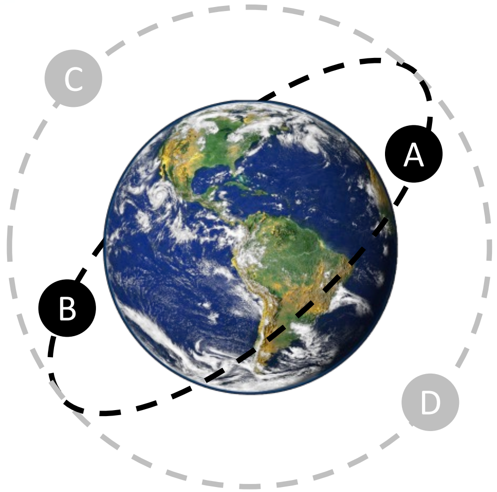


Point Target Look Diversity

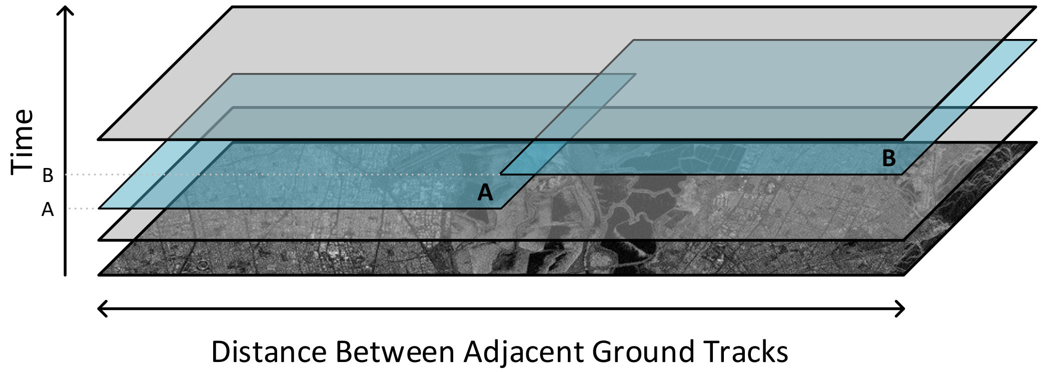
Lowered Inclination Architectures

Capability	Ranking
Continuity	
Coverage	
Error Reduction	
Look Diversity	

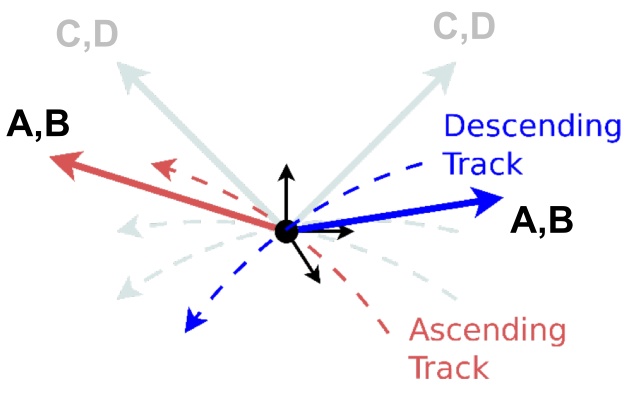
- Lower the orbital inclination of the constellation to improve mid-latitude look diversity
- Would open larger holes over the poles
- Would provide faster non-interferometric revisit times
- Would likely need to be in conjunction with other open measurements in a sun-sync orbit
- First architecture shown that would depend on other instruments and programs to meet the full needs of SDC



Orbital Plane Spacing



Ground Track Spacing

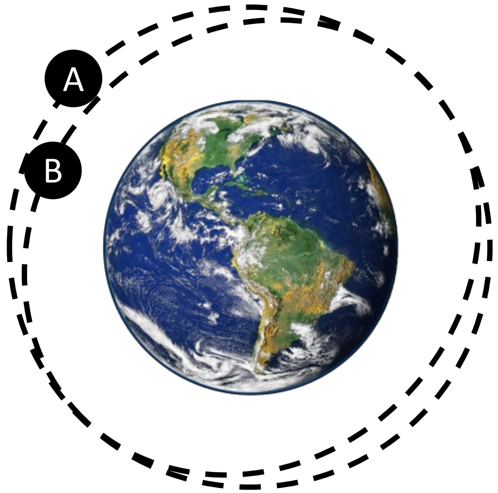


Point Target Look Diversity

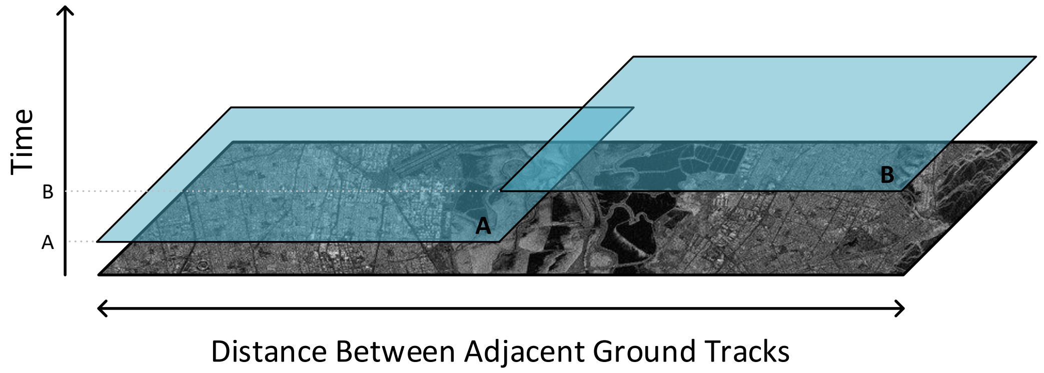
Helical Orbit Formation Architectures

Capability	Ranking
Continuity	
Coverage	
Error Reduction	
Look Diversity	

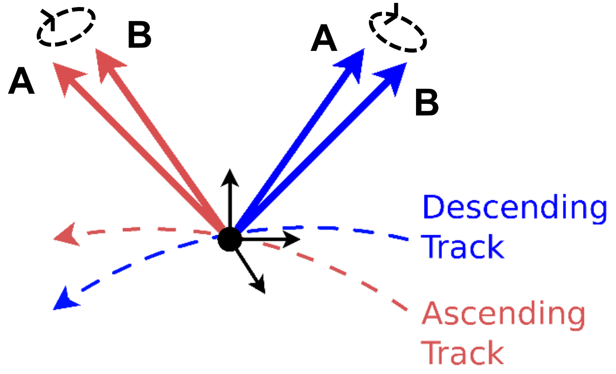
- Operate multiple spacecraft in close proximity using a helical orbit (similar to TanDEM-X)
- Enables a variety of baselines for more than repeat-pass interferometry
- With enough spacecraft (>5), enables radar tomography for vegetation structure
- Modified zero-Doppler steering algorithms would lay down adjacent tracks for global coverage
- S/C diversity in this architecture does not lend itself as easily to atmospheric error correction or 3D deformation



Orbital Plane Spacing



Ground Track Spacing

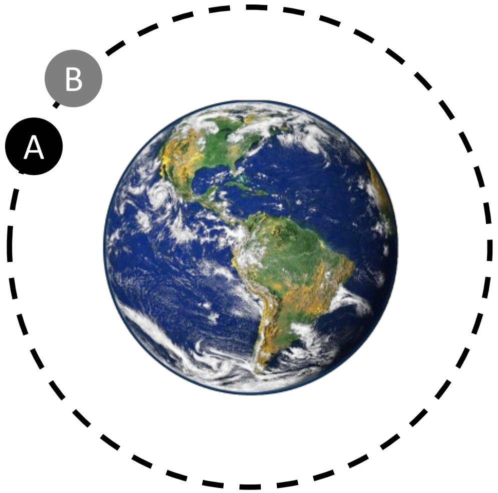


Point Target Look Diversity

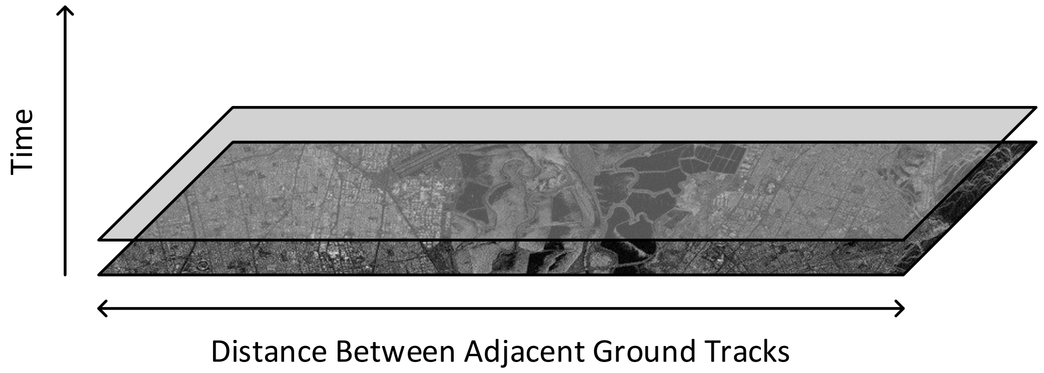
Dedicated Water Vapor Instrument Architectures

Capability	Ranking
Continuity	
Coverage	
Error Reduction	
Look Diversity	

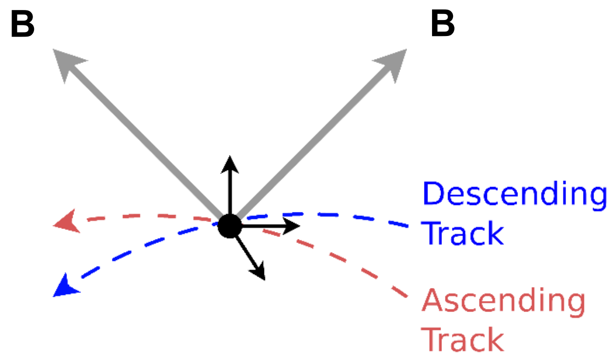
- A passive microwave instrument flying in formation with another SAR instrument
- Provides tropospheric delay estimation without adding to the SAR coverage rate
- Lowest cost option that could scale down to cubesat scale in certain situations
- Dependent on either other SDC or international SAR observatories to complete the architecture



Orbital Plane Spacing



Ground Track Spacing

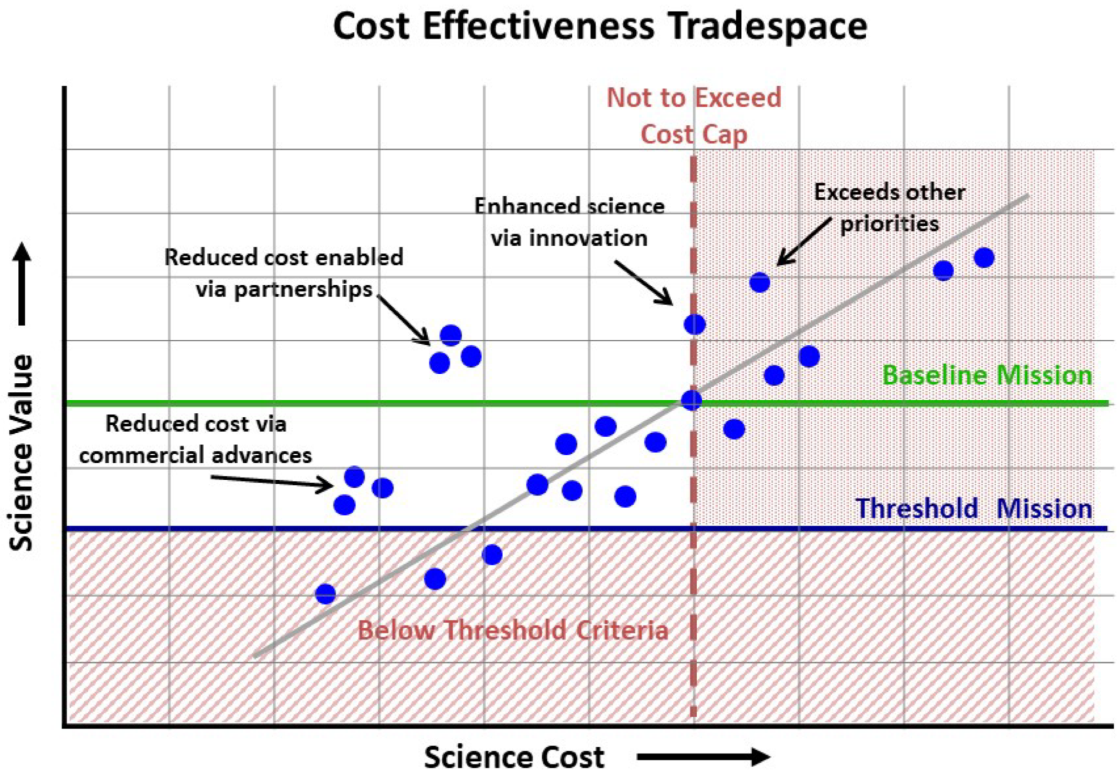


Point Target Look Diversity

Architecture Downselection

- Architecture selection will also take a systematic approach called the “Value Framework”
- Definition of the value framework must be complete by the end of phase 2 (March 2022)
- Elements for evaluation include:

1. Cost
2. Risk (both mission and implementation risks)
3. Science and application responsiveness to the SATM:
   1. **Utility**: how important is the measurement capability to addressing the science/application objective
   2. **Quality**: how well does the measurement estimate the geophysical quantity (performance tool results)
4. Programmatic factors
   1. How does the architecture fit into the program of record?
   2. What international partnerships are available?



Summary

- The prior rankings are representative, but value assessment comes from the community
- Many opportunities for cross-pollination between the architecture examples shown
- Keep giving us your feedback on which capabilities matter the most for your science
- Without your feedback, other factors (namely cost) will drive the value selection