Surface Deformation and Change (SDC)

Part 2: Observing Capabilities and Systems

The SDC Study Team, Jet Propulsion Laboratory, California Institute of Technology

The Need to Prioritize Observables: The wide range of Solid Earth phenomena calls for observing capabilities that are challenging to reconcile: global coverage vs. fast repeat; decadal time series vs. innovative look geometries. Measurement of land surface deformation due to volcanic or earthquake activity needs at least two components of land surface deformation and strain localization (e.g., surface fracturing) over length scales ranging from 10 m to 100s of km and a precision of a few millimeters at a sampling frequency related to the duration of the activity (days to months), to be regionally-sampled on a background of global coverage. In this example, fast repeat measurements would need to be acquired over a specific area at a specific time during a volcanic eruption, or shortly after an earthquake to capture post-seismic deformation. Yet, interpreting such observations usefully would not be possible without global coverage preceding these events to provide a baseline for comparison. Indeed, more than 10 years of observations would be needed to measure inter-seismic deformation. Ideally, an observing system that combines global coverage, a quick-response capability, and continuity with the Program of Record (PoR), would address these needs. The challenge of designing such a system illustrates well the necessity of prioritizing scientific and application objectives and accommodating competing demands.

Trade-offs of Observing Systems: The observation capabilities identified by SDC's Solid Earth focus group guided the design of the observing systems. The diverse set of observables targeted by SDC necessitated the consideration of several observing systems, as no single approach can implement all capabilities. Finding balance between data continuity and pushing the bounds of new science is also a key challenge for the sizable Solid Earth community. Systems we consider are constellations composed of several relatively smaller instruments (compared with NISAR and other flagship missions). While each smaller payload has limited capability compared with a flagship mission, as a part of a constellation they enable unique capabilities and offer observational flexibility. Many of the capabilities considered involve trade-offs among the number of satellites composing an observing system, the swath width covered, viewing angles, and revisit time, all of which combine to define the attributes of an SDC observing system. Table 2.1 shows the capabilities most sought after, and the performance of the main proposed observing systems in realizing them.

Polar vs. Non-Polar Observing Systems: The Study considered non-sun-synchronous constellations with lower inclination orbits as a means for delivering fast revisit and better north-south geodetic accuracy. These concepts were not favored as they could not also serve the polar ice community. We felt that SDC must serve both Solid Earth and Cryosphere communities to be viable programmatically.

Drivers of Cost: The largest driver of cost that we identified is coverage and associated volumes of data. Combining global spatial coverage with faster revisit raises the challenge of increasing the coverage rate of the mission. There are two options to increase coverage rate when a system operates continuously over all land: increase the swath width of a single spacecraft while maintaining performance or increase the number of satellites making the observation. Both incur added costs. The Study considered degrading the radar instrument capabilities to reduce overall noise performance, affecting both the backscatter interpretability and increasing phase noise for interferometry. As InSAR measurement requirements often combine many pixels and time steps, we thought that geodetic performance would be adequate if the overall cost could be reduced. The Study, however, does not recommend sacrificing backscatter performance to only serve the needs of InSAR geodesy. Cost savings were not sufficient to justify the loss of the applications and Ecosystems science that the backscatter provides.

Role of Commercial SAR: An SDC Commercial SAR subgroup was tasked with evaluating the current landscape of the SAR/InSAR industry to assess potential commercial satellite contributions to SDC's science and applications. The assessment found that existing commercial systems have significant limitations. Those are due to the different design goals between current commercial systems and SDC:

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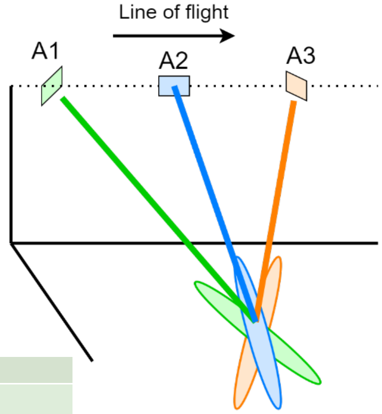
commercial systems prioritize targeted high-resolution, non-interferometric observations at short wavelengths (X-band) with a daily or faster revisit, while SDC focuses on global, moderate-resolution, and interferometric observations at longer wavelengths (L- or S-band). Still, commercial systems have the potential to offer the ability to *augment* any of SDC's proposed observing systems to increase local revisit rates (e.g., urgent response), provide frequency diversity, or deliver unique datasets to address particular challenges (e.g., long-dwell spotlight or hourly imagery).

Virtual Constellations: Developing a system that integrates geodetic deformation products could give value beyond the sum of individual observatory data and allow SDC to lower its coverage rate to support targeted enhancements to the aggregate system. This framework would provide direction for SDC to assess the maximum benefit to the PoR, and may reduce cost with the lower coverage rate. Such a framework would be similar to NASA's Integrated Multi-satellite Retrievals for Global Precipitation Measurement (IMERG).

Table 2.1: Observing systems proposed by the SDC Study. L-band (or potentially S-band) are recommended for all observing systems, as well single polarization. The colored ovals indicate examples of the observables that can be addressed by the observing systems. The measurement parameters of each observable, and other details, are given in Part 1.

Observing 3D deformation in real time

- Multi-squint formation of 3 satellites covering 1/3 NISAR swath
- Independent squinted views improve accuracy of North-South displacement (focused mode; as in figure)
- Combines with ROSE-L observations to increase time-series density globally (extended mode)
- Allows re-projecting the displacement along any line of sight for comparison with other systems



Strengths
- New science with the study of motion in any direction
- Better single interferogram accuracy with troposphere error removal

Weaknesses
- Strengths come at the expense of coverage
- For RL: No control over primary mission plan (NASA would be the junior partner)

Scenario favorable for selection

Desire for new science with independence of observation plan and a budget not strictly tied to 2017 decadal survey limit ($500M)

Architectures:

Multi-squint **MS**

ROSE-L co-flyers **RL**

Science Enabled

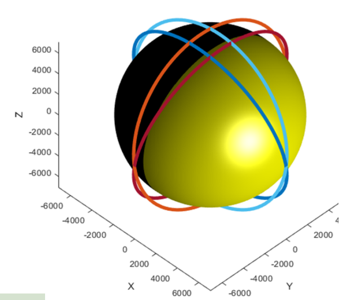
Understanding 3D deformation is important for the study and modeling of the earthquake cycle, volcanic systems, groundwater flow.

Observables

Volcanoes Earthquakes; Volcano, Earthquake Hazards; Landscape Change; Groundwater Flow-Geology; Groundwater Reservoirs; Coastal Vertical Motion; Shallow Aquifer Fluxes; Water Flow Impact on Earthquakes; Mapping Resources

Intermittent sub-daily observations in select areas

- Formation of 8 satellites in 4 orbital planes delivers 6-hour repeats for 2 days out of a 12-day cycle
- By deferring many of the original SDC objectives to ROSE-L, the instrument can be specifically tuned for the fast repeat measurement making it significantly cheaper
- Targets are coastal regions and specific transient interest regions rather than global collection



Strengths
- Enables observations on a new, faster time scale with the potential for discovery

Weaknesses
- Leaves a majority of SDC objectives to ROSE-L

Scenario favorable for selection

Desire to pursue new science while leaving a majority of the SDC objectives defined in the decadal survey to ROSE-L

Architecture:

Sub-daily **SD**

Science Enabled

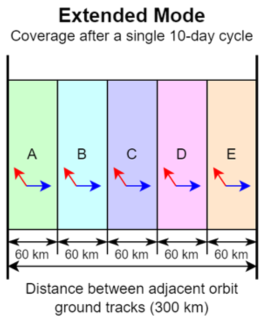
Dynamic phenomena such as rapid transient deformation and tidally-driven coastal process that vary over the course of a day that benefit from intermittent, globally-distributed, sub-daily observations that avoid aliasing of the deformation signal.

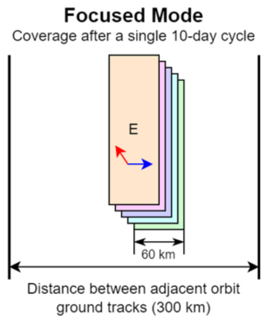
Observables

Volcanic, Earthquake Hazards; Deformation after Disaster; Landslides Hazards; Volcanoes Earthquakes; Groundwater Flow-Geology

Reduced local revisit

- Formation of 5 satellites distributed evenly in the same 10-day orbital plane delivers 40% better revisit time/coverage than NISAR.
- in a disaster, satellites can steer to the same look angle to make 2-day interferometry at the expense of gaps around that urgent response area.
- Revisit latency decreases to less than 12 hours compared with 3-4 days for NISAR





Strengths
- Maintains independent global coverage

Weaknesses
- Does little to leverage international missions

Scenario favorable for selection

Desire for a left-looking mission with strong applications mandate where the budget is not tied to the strict limit given in the 2017 decadal survey

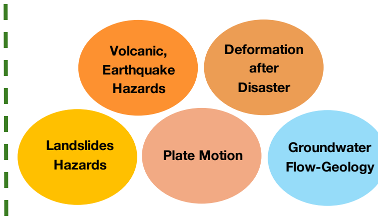
Architecture:

Split Swath **SS**

Science Enabled

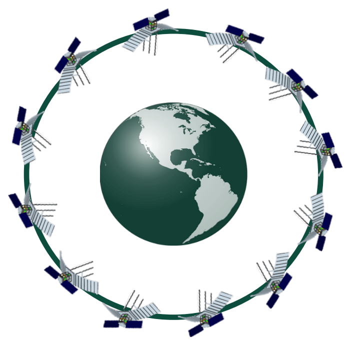
The ability to increase temporal resolution on local scales can help with rapid response and study of disasters while still providing background global measurements.

Observables



Flexible acquisition strategy

- Lower orbital duty cycle (15%) requires 12 satellites to achieve global coverage and producing the minimum viable instrument for SDC geodetic goals
- Reduced antenna area and transmit power lowers SNR to the minimum for InSAR coherence
- Instruments most similar to commercial designs that would allow building to spec after a NASA pathfinder
- Lack of polarimetry and reduced radiometric performance defers some science goals to ROSE-L



Strengths
- Targeted local revisits at a daily rate
- Path to constellation replenishment with spec design

Weaknesses
- Reduced instrument performance leaves out many science and applications goals of other disciplines (e.g., Ecosystems)

Scenario favorable for selection

Desire to meet the cost cap provided in the 2017 decadal survey while providing a spec for future constellation maintenance

Architecture:

Low duty cycle **LD**

Science Enabled

A variety of Solid Earth observables, including transient deformation, disasters, can be studied using customized observational campaigns, where time between observations is temporarily reduced to daily revisit.

Observables