Surface Deformation and Change (SDC)
Part 1: Science and Applications

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Status and Approach: As SDC's Mission Study focuses its attention on NASA's forthcoming 2027 Earth Decadal Survey, the study team continues exploring the lessons to be learned from the imminent NISAR mission, and the potential of international partnerships. The continued investigations are anchored in the geophysical observables, and their measurement parameters, that the Study explored since its inception in 2018. The set of observables related to Solid Earth is the focus of the present white paper. The observing systems to capture them are described in a companion paper (Part 2: Observing Capabilities and Systems). Our exploration of SDC's Solid Earth geophysical observables began with the science and applications recommendations of the 2017 Decadal Survey. We asked a group of subject-matter experts to examine and further refine the observables and their measurement parameters. In parallel, we sought input from the larger community through workshops, town halls and questionnaires. A key attribute of our approach is flexibility: to balance continuity of measurements and new science; to adapt to the evolution of the Program of Record (PoR) and of the relevant science; to respond to growing emphasis on applications; to take advantage of possible international partnerships and commercial sector capabilities; and to be resilient in face of variable budgetary constraints.

Desired Observables: The objectives of SDC's Solid Earth focus area comprise landscape change due to tectonics, surface processes, and human activities. Geophysical observables that correspond to these objectives include land surface deformation due to volcanic activity and crustal processes throughout the earthquake cycle. Vertical motion of land along coastlines, and in areas of groundwater extraction and replenishment, is also of much community interest. During our analyses, it was useful to put Solid Earth observables into two distinct groups:

- Solid Earth research on landscape changes produced by abrupt events or by continuous reshaping of Earth's surface due to surface processes, tectonics, and human activity.
- Geohazard and disaster applications, focusing on the detection of volcanic eruption precursors; earthquake, volcano and tsunami response; and land subsidence including of coastal regions.

Table 1.1 shows SDC's Solid Earth observables and their baseline measurement parameters.

Recommended Observational Capabilities: Having identified the geophysical observables, SDC's Solid Earth focus group then outlined the priority observational capabilities needed to capture them and advance the Solid Earth science and applications objectives. These are:

- Faster temporal sampling than the current InSAR Program of Record, which includes ESA's Sentinel and NISAR. This is the highest observational priority, especially for earthquake and volcano processes. It is also important for maintaining signal coherence for the deformation time series.
- Measurement of the 3 components of deformation (beyond the line-of-sight displacements such as that obtained from ascending and descending passes). 3-D deformation is desired to disentangle the tectonic, volcanic, and hydrological processes occurring simultaneously in many regions. This capability could be an important contributor to enabling continuity and promoting the use of all available SAR mission data in the same Earth system model.
- Better corrections for the atmospheric delay when measuring surface deformation. Forward/backward squint may enable more reliable corrections of tropospheric effects.
- Maintaining a long-term time series needed to understand processes that occur on decadal and longer time scales.

The observing systems that can realize the recommended observational capabilities are described in the companion paper (Part 2: Observing Capabilities and Systems).

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Table 1.1: Solid Earth observables and their recommended baseline measurement parameters. L-band (potentially S-band) and single polarization are recommended for all observables. Observables are listed in descending order of importance according to the 2017 Decadal Survey and SDC's Solid Earth experts. Acronyms in the green rectangles refer to the architectures described in Part 2. These are MS: Multi-squint; RL: ROSE-L; SD: Sub-daily; SS: Split swath; LD: Low duty. CS and DS refer to the Common and Dispersed Swath modes.

Land Surface Deformation Due to Volcanic Systems and Earthquake Cycle

Volcanoes Earthquakes

Measurement Parameters

• ***Revisit time:*** Daily • ***Spatial resolution:*** 10 m (Volc.)/50 m (Earthq., 10 m near faults) • ***Latency***: Not a priority
• ***Accuracy***: Vertical: 1 mm; horizontal: 10 mm (Volc.)/5 mm (Earthq.) • ***Coverage***: Global

Details

Focus is on pre-, syn-, and post eruption land surface deformation, and on seismic activity of tectonically active areas. At least 2 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 1 mm (Volc.)/1–10 mm (Earthq.) at a sampling frequency related to the volcanic/seismic/tectonic activity. Regionally sampled global coverage. For earthquakes in particular: Ideally, resolution of 1 mm/week. Need more than 10 years of observations to measure interseismic deformation. Would like 3D measurements for resolving overlapping processes. Frequent revisit time will discriminate among different physical models of fault ruptures, postseismic processes, transient slip.

Favorable Architectures: MS, RL, SD

Volcanic and Earthquake Hazards

Volcanic, Earthquake Hazards

Measurement Parameters

• ***Revisit time:*** Sub-daily • ***Spatial resolution:*** 10 m • ***Latency***: 1–3 hours (<12 hours postseismic)
• ***Accuracy***: Vertical: 1 mm; horizontal: 1 cm (focus is on post-eruption surface deformation); Vertical: 1 cm; horizontal: 10 cm (focus is on damage to infrastructure following an earthquake) • ***Coverage***: Localized

Details

Frequent revisits will capture complex dynamics of magma migration in volcanic systems. Would like the ability to task measurements at sub-daily frequency during volcanic crises. Daily observations and low latency would improve response time for damage maps post-earthquake. Need to consider geolocation accuracy as well.

Favorable Architectures: SD, SS (CS), LD

Rapid Transient Deformation after Disasters

Deformation after Disaster

Measurement Parameters

• ***Revisit time:*** Daily • ***Spatial resolution:*** 10 m • ***Latency***: 3 hours (crisis, <2 days otherwise)
• ***Accuracy***: <1 cm per observation (monitor), <5 cm per observation (crisis and post-event) • ***Coverage***: Localized

Details

Transient processes following disasters to provide a rapid deformation map.

Favorable Architectures: SD, SS (CS), LD

Decadal Landscape Change

Landscape Change

Measurement Parameters

• ***Revisit time:*** Weekly • ***Spatial resolution:***10 m • ***Latency***: Not a priority
• ***Accuracy***: Vertical: 5–10 mm precision; horizontal: 10–50 mm precision • ***Coverage***: Global

Details

Higher spatial resolution would likely be more important than higher temporal resolution.

Favorable Architectures: MS, RL

Sea-level Rise: Vertical Motion of Land Along Coastlines

Coastal Vertical Motion

Measurement Parameters

• ***Revisit time:*** 6 days • ***Spatial resolution:*** 50 m (10 m in specific areas) • ***Latency***: Not a priority
• ***Accuracy***: Vertical: 5–10 mm precision, 1 mm/yr accuracy; horizontal: < 50 mm precision • ***Coverage***: Global coastlines

Details

Need to achieve 1 mm/yr with 10-year time series. Continuity with NISAR for long time series is important for measuring small, slow changes in rates. High temporal resolution, long time series can reduce uncertainty in small rates of vertical land motion along the coast.

Favorable Architectures: MS, RL

Landslides Hazards

Landslides Hazards

Measurement Parameters

• ***Revisit time:*** Sub-daily • ***Spatial resolution:*** 10 m • ***Latency***: Hours–days in case of hazard, otherwise, not a priority • ***Accuracy***: Vertical: 1 mm/yr; horizontal: 3 mm/yr • ***Coverage***: Global; localized in case of hazard

Details

At least 2 components of surface deformation at < 50 m spatial resolution and 1 mm/yr at a temporal frequency < seasonal. Would like 3D measurements for estimating landslide thickness with rheological models. 10-year long time series to achieve ~1 mm/yr accuracy. High temporal and spatial resolution will capture transient landslide movement, linkages to precipitation.

Favorable Architectures: SD, SS (CS), MS, RL

Plate Motion and Deformation

Plate Motion

Measurement Parameters

- ***Revisit time:*** Monthly • ***Spatial resolution:*** 100 m • ***Latency***: Not a priority
- ***Accuracy***: Vertical: 10 mm precision; horizontal: 100 mm precision • ***Coverage***: Global

Details

Steady velocity measurement of convection scale features - vertical measurement, epeirogenic uplift.

Favorable Architectures

SS (DS) | LD | MS | RL

Groundwater Flow and its Impact on Geological Processes and Water Supply

Groundwater Flow-Geology

Measurement Parameters

- ***Revisit time:*** Daily • ***Spatial resolution:*** 10 m • ***Latency***: Not a priority
- ***Accuracy***: Vertical: 1 cm/yr; horizontal: 2 mm/yr • ***Coverage***: Global

Details

Continuity with NISAR for long time series is important for seeing decadal scale changes. Three dimensional measurements for resolving overlapping processes. Frequent revisit time, long time series will constrain mechanics of confined aquifers and their interaction with fault structures.

Favorable Architectures

MS | RL | SS (CS) | SD

Fluxes In and Out of Groundwater Systems

Groundwater Reservoirs

Measurement Parameters

- ***Revisit time:*** 6–12 days • ***Spatial resolution:*** 10 m • ***Latency***: Not a priority
- ***Accuracy***: Vertical: 5–10 mm precision; horizontal: < 50 mm precision; 1 mm/yr accuracy • ***Coverage***: Overactive reservoirs, managed watersheds, other watersheds of interest

Details

Land surface deformation in relation to spatiotemporal distribution of subsidence/uplift.

Favorable Architectures

MS | RL

Fluid Fluxes in Shallow Aquifers

Shallow Aquifer Fluxes

Measurement Parameters

- ***Revisit time:*** Weekly • ***Spatial resolution:*** 5 m • ***Latency***: Not a priority
- ***Accuracy***: Vertical: 3 mm/yr; horizontal: 2–3 mm/yr • ***Coverage***: Overactive reservoirs

Details

Deformation from fluid fluxes in relation to spatiotemporal distribution of subsidence/uplift.

Favorable Architectures

MS | RL

Impact of Human Activities and Water Flow on Earthquakes

Water Flow Impact on Earthquakes

Measurement Parameters

- ***Revisit time:*** Weekly • ***Spatial resolution:*** 5 m • ***Latency***: Not a priority
- ***Accuracy***: Vertical: 3 mm/yr; horizontal: 2–3 mm/yr • ***Coverage***: Global

Details

Vertical surface deformation in relaton to spatiotemporal distribution of subsidence/uplift.

Favorable Architectures

MS | RL

Map Energy, Mineral, Agricultural and Natural Resources for Improved Management

Mapping Resources

Measurement Parameters

- ***Revisit time:*** Weekly • ***Spatial resolution:*** 30 m • ***Latency***: Not a priority
- ***Accuracy***: Vertical:1 cm/yr; horizontal: 2–3 mm/yr • ***Coverage***: Global

Details

Land surface deformation in relation to spatiotemporal distribution of subsidence/uplift.

Favorable Architectures

MS | RL