Surface Deformation and Change Science and Applications Traceability Matrix

SDC R&A Team

Co-Leads - Ala Khazendar, Andrew Molthan, Jeanne Sauber

Team Members - Jordan Bell, Claudia Carabajal, Maggi Glasscoe, Anita LeRoy, Ronan Lucey, Laura Rogers, Emily Sylak-Glassman

July 14, 2021

Surface Deformation and Change Science and Applications Traceability Matrix

The SDC Phase 1 SATM reflects and distills the community's input received through in-person and virtual workshops, surveys and polls, and the work of SDC's discipline-themed focus groups. The focus groups are as follows: Hydrology, Cryosphere, Ecosystems, Solid Earth, and Geohazards. SDC's Phase 1 SATM is an augmented and deepened version of the 2017 Decadal Survey's (DS) SATM. Starting from the DS's Science and Application Objectives, the Geophysical Observables provided were expanded (mostly to include amplitude-based measurements, as directed by NASA) and then nuanced, and the corresponding measurement parameters refined.

The DS considered 5 top-level, interdisciplinary science and application topics in the process of developing priorities. The letters denoting the topics in the following list are used as reference throughout the SATM:

Global Hydrological Cycles and Water Resources ***(H)***: The movement, distribution, and availability of water and how these are changing over time.

Weather and Air Quality—Minutes to Subseasonal ***(W)***: Atmospheric Dynamics, Thermodynamics, Chemistry, and their interactions at land and ocean interfaces.

Marine and Terrestrial Ecosystems and Natural Resource Management ***(E)***: Biogeochemical Cycles, Ecosystem Functioning, Biodiversity, and factors that influence health and ecosystem services.

Climate Variability and Change: *Seasonal to Centennial* ***(C)***: Forcings and Feedbacks of the Ocean, Atmosphere, Land, and Cryosphere within the Coupled Climate System.

Earth Surface and Interior: Dynamics and Hazards ***(S)***: Core, mantle, lithosphere, and surface processes, system interactions, and the hazards they generate.

Surface Deformation and Change Science and Applications Traceability Matrix

Within each topic, the DS identified a set of major ***Societal or Science Question/Goals*** (listed as questions in the first column of the individual SATM tables). Each one of these major goals was in turn expressed in greater detail as a number of ***Science and Applications Objectives*** (listed in column 2 of the individual SATM tables) that are needed to address the related goal. Those objectives were prioritized by the DS as ***Most Important, Very Important, or Important.*** The ***Geophysical Observables*** are the parameters to be observed to pursue the related objective, and their specifications are listed as the ***Measurement Parameters***.

Phase 2 Plans of the SDC Study

The focus of Phase 2 is to establish a Value Framework that enables assessments of how well different mission architectures meet the science and application objectives enunciated in SDC's SATM, hence informing the down-selection process. To that purpose, Phase 2 will embark on the following activities:

- Organize community meetings to review the priority ranking assigned to the different geophysical observables associated with each Science/Applications Objective.
- Hold application-focused workshops to develop a value rating approach to inform the architecture selection process, and to establish links with NISAR applications, highlighting how the expanded SDC capabilities can serve those and enhanced applications goals.
- Building on the above activities, develop a value framework to prioritize the desired science and application capabilities to determine the most appropriate/feasible mission architecture.
- Establish pathways for further community participation in the Phase 2 SATM activities described above.
- Communicate the conclusions of the above activities to SDC's Value Framework team to inform decision making and down-selecting candidate architectures.

Table of Contents
SDC SATM

Navigating the SDC SATM

Throughout the PowerPoint, clicking the Thematic Area logos on the bottom right corner of the slide will take you to their respective home pages.

Hydrology Weather Ecosystems Cryosphere Solid Earth

Clicking the Home button in the bottom right corner of the slide will take you to the thematic areas main page.

Clicking on the smaller logo next to an application objective on any of the thematic area slides will take you to that specific objective's slide.

Some application questions were addressed by multiple focus groups. A box will show on bottom of slide allowing to click to view the other group's comments, if applicable. Clicking on the Rings logo allows you to jump to the full duplicate slide menu.

SDC Necessity and Decadal Survey Importance are color coded in the bottom left corner of the slide.

Most Important
Very Important
Important

Global Hydrological Cycles & Water Resources (H)
(Also referred to as Hydrology)

Weather & Air Quality (W)
(Also referred to as Weather)

Marine & Terrestrial Ecosystems & Natural Resource Management (E)
(Also referred to as Ecosystems)

Climate Variability & Change – Seasonal to Centennial (C)
(Also referred to as Cryosphere)

Earth Surface & Interior – Dynamics (S)
(Also referred to as Solid Earth)

Key Terms – Non-Measurement Features

Geophysical Observable: The geophysical parameter to be detected in order to pursue the related Earth Science/Applications objective.

Decadal Survey (DS) Science Variable: A specific objective needed to address the related science or societal question, or in other words, the top-level science or applications question driving the research need.
Example:
The Decadal Survey provides us with a top-level question:
S-1: “Accurately forecast geologic hazards in a relevant time frame.”
The Decadal Survey requests the following Science Variables:
S-1a relates to measuring volcanoes and their surface deformation
S-1b relates to forecast and measurement of seismic activity
S-1c relates to forecast and monitoring of landslides
S-1d relates to forecast of tsunamis

DS Importance: The science and application importance per the Decadal Survey.

SDC Necessity: The relative importance of the Geophysical Observable to help achieve the Science and Application objective. Scale: Most Important > Very Important > Important.

Key Terms – Measurement Features

Bands: Number and range of wavelengths (or frequencies) of the electromagnetic waves transmitted and/or received by the instrument. Commonly referred to as letters designating a broad range of wavelengths and associated with different applications (e.g. X, C, S, L). These bands often have different degrees of penetration for clouds, precipitation, vegetation, and interactions with the Earth's surface and thus vary in their research and application potential. Desired bands are listed.

Polarization: The direction of travel of an electromagnetic wave - can be vertical (V) or horizontal (H). Single polarization (pol) - transmits and receives a single polarization, typically the same direction (VV) or (HH). Dual polarization – transmits in one polarization but receive in two (HH, HV) or (VH, VV). Quad polarization - transmits and receives two polarizations – (HH, HV, VH, and VV). Certain polarizations and bands are preferable for specific applications. Desired polarizations are listed.

Polarization Taxonomy:
Quad: Quad pol required. Can be a substitute for quasi quad, any dual pol, any single pol.
Quasi-Quad: quasi-quad pol required. Can be a substitute for dual pol and single pol
Dual Pol: HH/HV or VV/VH perfectly substitutable
HH/HV-preferred: HH/HV is preferred, but VH/VV can substitute
VH/VV-preferred: VH/VV is preferred, but HH/HV can substitute
HH/HV-required: HH/HV required and VV/VH not substitutable
VH/VV-required: VH/VV required and HH/HV not substitutable
Single pol (any): HH and VV are substitutable
HH-preferred: HH preferred, but can substitute VV
VV-preferred: VV preferred, but can substitute HH
HH-required: HH required, VV not substitutable
VV-required: VV required, HH not substitutable

Key Terms – Measurement Features

Horizontal Spatial Resolution: A measure of the smallest object that can be resolved by the sensor, or the ground area imaged, or the linear dimension on the ground represented by each pixel. This is the measurement spatial resolution, not the instrument resolution.

Revisit Time: The desired time interval between collection of observations with the same characteristics (viewing angle, resolution, etc.) over a specific location. As an example, while current ESA Sentinel-1 coverage may view a point on the Earth multiple times, viewing the same location with the same viewing geometry is currently a *revisit time* of XX days.

Latency: The desired time interval between an observation being collected by the sensor and the delivery of a given data product to the scientific user or application user community. Latency may differ between delivery of 'raw' information (Level 0) and higher-level products requiring multiple observations or ancillary data.

Accuracy: Difference between a measurement and the true value. Can be measured by a percentage difference from the true value, a distance from the true value, as a rate over time compared to the true rate over time, etc.

Coverage/Continuity: The geographical regions and repeat time provided by uninterrupted collection of observations over a period of time.

Comments/Other: Additional important information not covered by the other columns.

Surface Deformation and Change (SDC) Designated Observable Study Plan

2017 Earth Science Decadal Survey

DS Science Variable	DS Importance	SDC Necessity	Recommended Bands	Recommended Polarization	Horizontal Spatial Resolution	Revisit Time	Latency	Accuracy	Coverage/ Continuity	Comments/Other
Snow Water Equivalent (SWE) (H-1c)	Most Important	Most Important	L-band	VV-preferred	Minimum: 4 km Enhanced: 1 km 100 m in mountains	3-7 Days	1 Week	20%	Global; Mountains	Depth/SWE change retrieval through InSAR phase change. In-situ and modeling for phase ambiguity, initial density estimate.
SWE (H-1c)	Most Important	Most Important	X-band K_u-band	VV/VH-preferred	Minimum: 4 km Enhanced: 1 km 100 m in mountains	3-7 Days	1 Week	10%	Global; Mountains	SWE retrieval from multi-frequency, multi-pol backscatter. Modeling for initial microstructure estimate.
Latent heat flux (soil moisture) (H-2a)	Very Important	Important	L-band	Quad	200 m–1 km	Sub-Daily-Daily	1 Week	0.04 m^3/m^3	Global	Surface and root-zone soil moisture. Root-zone soil moisture is modeled using surface estimates. Vegetation information from quad pol is desired.
Recharge rates (soil moisture) (H-2c)	Most Important	Most Important	L-band	Quad	200 m–1 km	3-7 Days	1 Week	0.04 m^3/m^3	Global	Surface and root-zone soil moisture. Root-zone soil moisture is modeled using surface estimates.
Fire prediction (fuel load) (H-4d)	Important	Important	L-band	Quad	200 m–1 km	3-7 Days	1 Week	0.06 m^3/m^3	Global	Surface and root-zone soil moisture. Root-zone soil moisture is modeled using surface estimates. Vegetation information from quad pol is desired.
Drought monitoring (soil moisture) (H-4c)	Important	Very Important	L-band	Quad	1-10 km	Weekly	1 Week	0.06 m^3/m^3	Global	Surface and root-zone soil moisture. Root-zone soil moisture is modeled using surface estimates.
Recharge rates (Groundwater subsidence) (H-2c)	Most Important	Most Important	L-band	Single pol (any)	100 m	3-7 Days	1-2 Days	1cm	Global	Combine with GRACE-FO for mass change, long continuous record needed
Inundated area (H-4a, H-4b)	Very Important	Most Important	L-band	Minimum: Dual Pol Enhanced: Quad	10 m	Sub-Daily	<2 Hours	10cm	Global	

DS Science Variable	DS Importance	SDC Necessity	Recommended Bands	Recommended Polarization	Horizontal Spatial Resolution	Revisit Time	Latency	Accuracy	Coverage/ Continuity	Comments/Other
Energy balance (soil moisture) (W-3a)	Very Important	Important	L-band	Quad	1 km	Sub-Daily-Daily	1 Week	0.04 m^3/m^3	Global	Surface and root-zone soil moisture. Root-zone soil moisture is modeled using surface estimates. Vegetation information from quad pol is desired.
Weather prediction (soil moisture) (W-2a)	Most Important	Important	L-band	Quad	1-10 km	Sub-Daily-Daily	1-2 Days	0.04 m^3/m^3	Global	Surface and root-zone soil moisture. Root-zone soil moisture is modeled using surface estimates.

DS Science Variable	DS Importance	SDC Necessity	Recommended Bands	Recommended Polarization	Horizontal Spatial Resolution	Revisit Time	Latency	Accuracy	Coverage/ Continuity	Comments/Other
Absolute Soil Moisture (E-1d)	Important	Very Important	L-band, S-band	Minimum: HH-preferred Enhanced: Quasi-Quad	≤ 20 m	3-6 Days	1-3 Days	6% accuracy in non-forested regions	Global	
Relative Soil Moisture (E-3a)	Most Important	Most Important	L-band, S-band	Minimum: HH-preferred Enhanced: Quasi-Quad	≤ 20 m	3-6 Days	1-3 Days	6% accuracy in non-forested regions	Global	
Freeze/Thaw Boundary Dynamics (Frozen/Not Frozen) (C-3c)	Important	Very Important	L-band, S-band	Minimum: HH-preferred Enhanced: Quasi-Quad	≤ 20 m	7-14 Days	7 Days	80% classification accuracy	Global	Water Storage/Supply
Vegetation Structure (canopy height & vertical distribution) (E-1b)	Most Important	Most Important	L-band	HH/HV-preferred	≤ 20 m	≤ 14 Days	14 Days	The greater of 20% or 5m vertical error.	Global	Timber Stocks and management
Above ground vegetation biomass & biomass change (E-4a)	Important	Most Important	L-band	HH/HV-preferred	≤ 20 m	Minimum: 14 Days Enhanced: <7 Days	14 Days	20 Mg/ha for areas of biomass <100 Mg/ha	Global	Timber Stocks

DS Science Variable	DS Importance	SDC Necessity	Recommended Bands	Recommended Polarization	Horizontal Spatial Resolution	Revisit Time	Latency	Accuracy	Coverage/ Continuity	Comments/Other
Change in land cover due to flooding, wildfire, wind, insects, anthropogenic (E-5b)	Important	Most Important	L-band	HH/HV-preferred	≤ 20 m	≤ 14 Days	14 Days	80% Extent Accuracy at 1 ha	Global	Hazard Monitoring – Flooding, Wildfire, Severe Storms, Ecological, Anthropogenic
Agricultural Management (Active crop area, crop class, crop yield, crop practices) (H-2c)	Most Important	Very Important	L-band	HH/HV-preferred	≤ 20 m	≤ 14 Days	14 Days	80% or better Classification Accuracy	Global	Food Security and Supply
Classification of rice and aquaculture (H-2c)	Most Important	Most Important	L-band, C-band, S-band	HH/HV-preferred	≤ 20 m	Minimum: <14 Days Enhanced: <7 Days	14 Days	80% Extent Accuracy at 1 ha	Global	Food Security and Supply
Measure inland and coastal wetlands areas (H-4a)	Very Important	Most Important	L-band	HH/HV-preferred	≤ 20 m	Minimum: <14 Days Enhanced: <7 Days	14 Days	80% Extent Accuracy at 1 ha	Global	Coastal flooding and storm vulnerability Flood Mapping/prediction
Measure relative water level changes in wetlands (E-5a)	Important	Most Important	L-band	HH/HV-preferred	≤ 20 m	Minimum: <14 Days Enhanced: <7 Days	14 Days	80% Extent Accuracy at 1 ha	Global	Coastal flooding and storm vulnerability Flood Mapping/prediction

DS Science Variable	DS Importance	SDC Necessity	Recommended Bands	Recommended Polarization	Horizontal Spatial Resolution	Revisit Time	Latency	Accuracy	Coverage/ Continuity	Comments/Other
Mean flow of fast flowing outlet glaciers, grounded and floating (>50 m/yr) (C-1c and S-3a)	Most Important	Most Important	L-band	Single pol (any)	100 m	Weekly	3 Months	10 m/yr	Global	
Mean flow of slow flowing ice-sheet interiors (<50 m/yr) (C-1c and S-3a)	Most Important	Very Important	L-band	Single pol (any)	500 m	Annually	3 Months	0.1 m/yr	Global	
Mean flow of large mountain glaciers (C-1c and S-3a)	Most Important	Very Important	L-band	Single pol (any)	50 m	Twice monthly	3 Months	10 m/yr	Global	
Strain rates at shear margins (grounded ice) (C-1c and S-3a)	Most Important	Very Important	L-band	Single pol (any)	100 m	Monthly	3 Months	10 m/yr Horizontal Precision	Global	
Strain rates associated with fracture and calving and ice mélange (C-1c and S-3a)	Most Important	Most Important	L-band	Single pol (any)	100 m	6 hours	3 Months	10 m/yr Horizontal Precision	Global	
Geometry of ice mélange (C-1c and S-3a)	Most Important	Very Important	L-band	Single pol (any)	10 m	6 hours	3 Months	10 m Horizontal	Global	
Tidal flexure in the grounding zones (50 km upstream and all floating) (C-1c and S-3a)	Most Important	Most Important	L-band	Single pol (any)	50 m	6 hours (select) Weekly (all)	3 Months	30mm Vertical Accuracy Between Acquisitions	Global	

DS Science Variable	DS Importance	SDC Necessity	Recommended Bands	Recommended Polarization	Horizontal Spatial Resolution	Revisit Time	Latency	Accuracy	Coverage/ Continuity	Comments/Other
Basal friction inverted from temporal changes in velocity (C-1c and S-3a)	Most Important	Most Important	L-band	Single pol (any)	100 m	6 hours	3 Months	10 m/yr	Global	
Elevation signal of interior sub-glacial lake drainage and filling (C-1c and S-3a)	Most Important	Important	L-band	Single pol (any)	50 m	Weekly	3 Months	30mm	Global	
Circumpolar fine scale sea ice motion & deformation (C-8a, C-8b, and C-8c)	Very Important	Most Important	L-band (Could be combined with C-band)	Single pol (any)	1 km	Daily	3 Months	100 m/day (both poles)	>85N & to 78S	
Sea ice ridge and lead evolution, polynya formation, brine formation, and heat flux (C-8a, C-8b, and C-8c)	Very Important	Most Important	L-band (Could be combined with C-band)	Single pol (any)	500 m	4-6 Hours	3 Months	10 m/day (relative)	Global, spring & winter	
Marginal/coastal sea ice zone mechanics and fluxes (C-8a, C-8b, and C-8c)	Very Important	Most Important	L-band (Could be combined with C-band)	Single pol (any)	100 m	4-6 Hours	3 Months	10 m/day (relative)	Global, spring & summer	
Sea ice formation and distribution (C-8a, C-8b, and C-8c)	Very Important	Very Important	L-band (Could be combined with C-band)	Single pol (any)	10-100 m	Daily	3 Months	TBD	Global, continuous	

DS Science Variable	DS Importance	SDC Necessity	Recommended Bands	Recommended Polarization	Horizontal Spatial Resolution	Revisit Time	Latency	Accuracy	Coverage/ Continuity	Comments/Other
Volcanic Systems and Hazards • Land surface deformation (S-1a) (S-2b)	Most Important Very Important	Most Important Very Important	L-band, S-band	Single pol (any)	10 m (SE) 10-100 m (GH)	Daily (SE) Sub-Daily-Weekly (GH)	Not a Priority (SE) 1-3 Hours (GH)	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 at a sampling frequency related to the volcanic activity. Regionally-sampled global coverage.	Global (SE) Localized (GH)	GH: Would like the ability to task measurements at sub-daily frequency during volcanic crises. Frequent revisit time will capture complex dynamics of magma migration in volcanic systems.
Earthquake Cycle and Hazards • Land surface deformation (S-1b) (S-2c)	Most Important Very Important	Most Important Most Important	L-band, S-band	Single pol (any)	50m, 10m near faults (SE) 10-30 m (GH)	Daily	Not a Priority (SE) <3 Hours coseismic, <12 Hours postseismic (GH)	At least 2 components of land surface deformation 10 m to 1000 km resolution and precision of 1-10 mm at a sampling frequency related to seismic/tectonic activity. Ideally, resolution of 1 mm/week. Need more than 10 years of observations to measure interseismic deformation	Global (SE) Localized (GH)	Would like 3D measurements for resolving overlapping processes. Frequent revisit time will discriminate between different physical models of fault ruptures, postseismic processes, transient slip. GH: Daily observations and low latency would improve response time for damage maps post-earthquake

DS Science Variable	DS Importance	SDC Necessity	Recommended Bands	Recommended Polarization	Horizontal Spatial Resolution	Revisit Time	Latency	Accuracy	Coverage/ Continuity	Comments/Other
Landslides Hazards • Land surface deformation (S-1c)	Very Important	Most Important (SE) Important (GH)	L-band, S-band	Single pol (any)	10 m	Sub-Daily-Monthly	Not a Priority (SE) Hours-Days (GH)	At least 2 components of land surface deformation at <50 m spatial resolution and 1 mm/yr at a temporal frequency <seasonal	Global (SE) Localized (GH)	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
Rapid Deformation Map Acquisitions (S-2a)	Most Important	Most Important	L-band, S-band	Single pol (any)	10-100 m (monitor) 10 m (crisis & post-event)	Weekly (monitor) Daily (crisis)	<2 Days (monitor) <3 Hours (crisis)	<1 cm per observation (monitor) <5 cm per observation (crisis & post-event)	Localized	
Sea Level Rise • 3D Surface deformation vectors on ice sheets • Ice Velocity (S-3a)	Most Important	Most Important	L-band, S-band	Single pol (any)	100 m	Monthly	Not a Priority	<1cm per year <10 cm/100 km^2 for ice sheets	Global	
Sea Level Rise • Vertical motion of land along coastlines (S-3b)	Most Important	Most Important	L-band, S-band	Single pol (any)	50 m 10 m (specific areas)	6-12 Days	Not a Priority	5-10 mm vertical precision <50 mm horizontal precision 1 mm/yr accuracy	Global Coastlines	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.

DS Science Variable	DS Importance	SDC Necessity	Recommended Bands	Recommended Polarization	Horizontal Spatial Resolution	Revisit Time	Latency	Accuracy	Coverage/ Continuity	Comments/Other
Landscape Change – Quantify global decadal landscape change • Land Surface Deformation • Soil Moisture (S-4a)	Most Important	Very Important	L-band, S-band	Single pol (any)	10 m	Weekly	Not a Priority	5-10 mm vertical, 10-50 mm horizontal precision	Global	Higher spatial resolution would likely be more important than higher temporal resolution.
Landscape Change – Content of Near Surface Materials • Reflectance for freeze/thaw • Reflectance for snow depth/snow water equivalent (S-4b)	Important	Most Important	K_a-band	Single pol (any)	100 m	Weekly	Not a Priority	<50 m horizontal	Global	PoR-17 (KaRIN, SWOT) PoR-12 (NISAR)
Energy Change – Effect of Convection • Plate motion and deformation (S-5a)	Very Important	Important	L-band	Single pol (any)	100 m	Monthly	Not a Priority	10 mm vertical, 100 mm horizontal precision	Global	Steady velocity measurement of convection scale features - vertical measurement, epeirogenic uplift.
Groundwater Flow and its impact on geological processes and water supply • Land surface deformation (S-6a)	Very Important	Most Important	L-band, S-band	Single pol (any)	10 m	Daily-Weekly	Not a Priority	1 cm/yr	Global	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.

DS Science Variable	DS Importance	SDC Necessity	Recommended Bands	Recommended Polarization	Horizontal Spatial Resolution	Revisit Time	Latency	Accuracy	Coverage/ Continuity	Comments/Other
Measure Fluxes in and out of groundwater system (S-6b)	Important	Most Important	L-band, S-band	Single pol (any)	10 m	6-12 Days	Not a Priority	5-10 mm vertical precision <50 mm horizontal precision 1 mm/yr accuracy	Overactive reservoirs, managed watersheds, other watersheds of interest	
Deformation from fluid fluxes in shallow aquifers (S-6c)	Important	Most Important	L-band, S-band	Single pol (any)	5 m	Weekly	Not a Priority	Spatiotemporal distribution of subsidence/uplift at 3 mm/yr vertical	Overactive reservoirs	
Vertical surface deformation – impact of human activities and water flow on earthquakes (S-6d)	Important	Very Important	L-band, S-band	Single pol (any)	5 m	Weekly	Not a Priority	Spatiotemporal distribution of subsidence/uplift at 3 mm/yr vertical	Global	5 m spatial resolution was not well understood by Solid Earth R&A group in 2019 workshop.
Discovery & Management – Map energy, mineral, agricultural and natural resources for improved management (S-7a)	Important	Important	L-band, S-band	Single pol (any)	30 m	Weekly	Not a Priority	Subsidence/uplift at 1 cm vertical	Global	

Global Hydrological Cycles & Water Resources (H)

Water Cycle (H-1)

- Snow & Ice (H-1c)

Anthropogenic Impact on Water Changes (H-2)

- Effect on latent heat flux, surface soil moisture (H-2a)
- Effect on groundwater recharge rates (H-2c)

Interaction of Water Cycle with other Earth Systems (H-4)

- Monitor & Understand Hazard Response and Flash Flood processes (H-4a, H-4b)
- Drought monitoring, soil moisture (H-4c)
- Fire occurrence, vegetation, soil moisture (H-4d)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION H-1. How is the water cycle changing? Are changes in evapotranspiration and precipitation accelerating, with greater rates of evapotranspiration and thereby precipitation, and how are these changes expressed in the space-time distribution of rainfall, snowfall, evapotranspiration, and the frequency and magnitude of extremes such as droughts and floods?	H-1c. Quantify rates of snow accumulation, snowmelt, ice melt, and sublimation from snow and ice worldwide at scales driven by topographic variability.	Seasonal evolution of basin snow water storage. Requires time series of snow water equivalent (SWE) during both accumulation and melt.	Global SWE at 1 (desirable) or 4 km (needed) resolution every 3-5 days, to 10% (desirable) or 20% (needed) accuracy for SWE values to 1 m. In mountains, SWE at ~100 m resolution suitable for SWE values to 2.5 m. L-band InSAR: change in SWE/depth	Existing passive microwave for global scale okay for SWE values to ~200 mm. Problematic for deep snow in heterogeneous terrain. (PoR-23) In mountains, measure depth (Ka band radar or laser altimeter) and density (SAR). (PoR-17), KaRIN, SWOT). L-band InSAR to measure change in depth/SWE.	L-band: Snow Depth/SWE change through interferometry. In-situ observations and modeling to handle phase ambiguities and provide initial density estimate. X- & Ku-band: Snow Water Equivalent retrieval through polarimetric backscatter and modeling. Δx, Δy: ~10m to increase SNR to 0.1 dB absolute for multi-band SWE retrieval and to increase SNR to 0.5 deg phase noise in interferometry. Δt: <3 days (desirable), ~7 week (needed) latency: ~ Week.

SDC Necessity: Most Important
Decadal Survey Importance: Most Important

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION H-2. Prediction of Changes. How do anthropogenic changes in climate, land use, water use, and water storage, interact and modify the water and energy cycles locally, regionally, and globally and what are the short- and long-term consequences?	H-2a. Quantify how changes in land use, water use, and water storage affect evapotranspiration rates, and how these in turn affect local and regional precipitation systems, groundwater recharge, temperature extremes, and carbon cycling.	Latent heat flux at 3 (desirable) to 6 hour (useful) resolution during daytime intervals and at 1 km spatial scale with better than 10 W/m^2 accuracy.	Soil moisture profile to 4% volumetric accuracy in top 1 m of the soil column.	Active microwave dual-channel L-band radar, VV, HH, and HV polarization at spatial resolution of 100 m to 1 km.	Active microwave would provide the desired spatial resolution. The revisit time would be a concern with a single platform and would require multiple copies. Data latency could be a concern. An accurate estimate of soil moisture is needed

SDC Necessity: Important
Decadal Survey Importance: Very Important

Anthropogenic Impact on Water Cycle (H-2c) (Hydrology Perspective)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION H-2. How do anthropogenic changes in climate, land use, water use, and water storage, interact and modify the water and energy cycles locally, regionally and globally and what are the short- and long-term consequences?	H-2c. Quantify how changes in land use, land cover, and water use related to agricultural activities, food production, and forest management affect water quality and especially groundwater recharge, threatening sustainability of future water supplies.	Recharge rates (i.e. space-time rates of change in groundwater storage and availability) at 1 (desired) up to 10 km (useful) scale globally at 10-day intervals with accuracy of better than ± 1 mm/day	Land surface deflection to 1 cm accuracy, 100 m spatial resolution. Soil moisture profile to 4% volumetric accuracy in top 1 m of the soil column.	L-band InSAR. Perhaps combined with airborne lidar. PoR-12 Combine InSAR-derived high-resolution deflection maps with synoptic GRACE/GRACE-FO measurements of gravity change (or mascons) Active microwave dual-channel L-band radar, VV, HH, and HV polarization at spatial resolution of 100 m to 1 km.	For L-band: Spatial resolution: 100m Accuracy: 1 cm Temporal sampling: 6-12 days Product latency: 1-2 days Note: Long-term continuous observations needed for quantifying anthropogenic effects on groundwater recharge. Active microwave would provide the desired spatial resolution. The revisit time would be a concern with a single platform and would require multiple copies. Data latency could be a concern.

SDC Necessity: Most Important
Decadal Survey Importance: Most Important

Objective also addressed by Ecosystems Group

Hazard Response (H-4a) (Hydrology Perspective)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION H-4. How does the water cycle interact with other Earth System processes to change the predictability and impacts of hazardous events and hazard-chains (e.g. floods, wildfires, landslides, coastal loss, subsidence, droughts, human health, and ecosystem health), and how do we improve preparedness and mitigation of water-related extreme events?	H-4a. Monitor and understand hazard response in rugged terrain and land-margins to heavy rainfall, temperature and evaporation extremes, and strong winds at multiple temporal and spatial scales.	Extent of floods.	Surface water inundated area Extent Change in extent Water level Water level change	For mapping flood extent: PoR12 Requires InSAR amplitude (high SNR) and phase	Crisis Stage: 10 m spatial resolution (3 m desired for improved DPM) < 4 hour sampling frequency < 2 hour product latency 2 cm accuracy Post-Crisis: 10 m spatial resolution 3-6 hour sampling frequency < 2 hour product latency 2 cm accuracy Other: Need a baseline image for pre-flood conditions; soil moisture needed for flood monitoring.

SDC Necessity: Most Important
Decadal Survey Importance: Very Important

Objective also addressed by Ecosystems Group

Quantify Key Variables & Processes (H-4b)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION H-4. How does the water cycle interact with other Earth System processes to change the predictability and impacts of hazardous events and hazard-chains (e.g. floods, wildfires, landslides, coastal loss, subsidence, droughts, human health, and ecosystem health), and how do we improve preparedness and mitigation of water-related extreme events?	H-4b. Quantify key meteorological, glaciological, and solid Earth dynamical and state variables and processes controlling flash floods and rapid hazard chains to improve detection, prediction, and preparedness.	Extent of floods.	Surface water inundated area Extent Change in extent Water level Water level change	For mapping flood extent: PoR12 Requires InSAR amplitude (high SNR) and phase	Crisis Stage: 10 m spatial resolution (3 m desired for improved DPM) < 4 hour sampling frequency < 2 hour product latency 2 cm accuracy Post-Crisis: 10 m spatial resolution 3-6 hour sampling frequency < 2 hour product latency 2 cm accuracy Other: Need a baseline image for pre-flood conditions; soil moisture needed for flood monitoring.

SDC Necessity: Very Important
Decadal Survey Importance: Important

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION H-4. How does the water cycle interact with other Earth system processes to change the predictability and impacts of hazardous events and hazard-chains (e.g., floods, wildfires, landslides, coastal loss, subsidence, droughts, human health, and ecosystem health), and how do we improve preparedness and mitigation of water-related extreme events?	H-4c. Improve drought monitoring to forecast short-term impacts more accurately and to assess potential mitigations. This is a critical socioeconomic priority that depends on success of addressing H-1b, H-1c, and H-2c	Soil moisture, vegetation moisture, cumulative evapotranspiration, and SWE.	Soil moisture profile to 4% volumetric accuracy in top 1 m of the soil column.	Active microwave dual-channel L- and P-band radar, VV, HH, and HV polarization at spatial resolution of 100 m to 1 km.	Active microwave would provide high spatial resolution (100-200 m) soil moisture. Revisit time of 6-12 days would be possible with a single spacecraft.

SDC Necessity: Important
Decadal Survey Importance: Important

Water Cycle (H-4d)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION H-4. How does the water cycle interact with other Earth system processes to change the predictability and impacts of hazardous events and hazard-chains (e.g., floods, wildfires, landslides, coastal loss, subsidence, droughts, human health, and ecosystem health), and how do we improve preparedness and mitigation of water-related extreme events?	H-4d. Understand linkages between anthropogenic modification of the land, including fire suppression, land use, and urbanization on frequency of, and response to, hazards. This is tightly linked to H-2a, H-2b, H-4a, H-4b, and H-4c	Dry fuel load, Soil Moisture	Soil moisture profile to 6% volumetric accuracy in top 1 m of the soil column.	Active microwave dual-channel L- and P-band radar, VV, HH, and HV polarization at spatial resolution of 100 m to 1 km.	Active microwave would provide high spatial resolution (100-200 m) soil moisture. Revisit time of 6-12 days would be possible with a single spacecraft. Data latency might be a concern too. Disaster related observations typically require higher revisit times and shorter latency.

SDC Necessity: Important
Decadal Survey Importance: Important

Weather & Air Quality: Minutes to Subseasonal (W)

Environmental Predictions (W-2)

- Initialization of soil moisture (W-2a)

Spatial Variations Impacts on Mass and Energy Transfers (W-3)

- Surface Energy Balance (W-3a)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION W-2. Larger Range Environmental Predictions. How can environmental predictions of weather and air quality be extended to seamlessly forecast Earth system conditions at lead times of 1 week to 2 months?	W-2a.Improve the observed and modeled representation of natural, low-frequency modes of weather/climate variability (e.g., MJO, ENSO), including upscale interactions between the large-scale circulation and organization of convection and slowly varying boundary processes to extend the lead time of useful prediction skills by 50% for forecast times of 1 week to 2 months. Advances require improved: (1) Process understanding and assimilation /modeling capabilities of atmospheric convection, mesoscale organization, and atmosphere and ocean boundary layers, (2) Global initial conditions relevant to these quantities/processes. Observations needed for boundary layer, surface conditions, and convection are described in W-1, W-3, and W-4, respectively.	Soil Moisture (surface to root-zone)	Soil moisture profile saturation, while 1 km resolution is desired, 25 km is useful.	Active microwave dual-channel L- and P-band radar, VV, HH, and HV polarization at spatial resolution of 100 m to 1 km.	Active microwave would provide high spatial resolution (100-200 m) soil moisture. Revisit time of 6-12 days would be possible with a single spacecraft. It is possible to model the root-zone soil moisture using surface observations.

SDC Necessity: Important
Decadal Survey Importance: Most Important

Surface Energy Balance (W-3)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION W-3. Surface Spatial Variations Impacts on Mass and Energy Transfers. How do spatial variations in surface characteristics (influencing ocean and atmospheric dynamics, thermal inertia, and water) modify transfer between domains (air, ocean, land, cryosphere) and thereby influence weather and air quality?	W-3a. Determine how spatial variability in surface characteristics modifies regional cycles of energy, water and momentum (stress) to an accuracy of 10 W/m^2 in the enthalpy flux, and 0.1 N/m^2 in stress, and observe total precipitation to an average accuracy of 15% over oceans and/or 25%over land and ice surfaces averaged over a 100 × 100 km region and 2-to 3-day time period.	Soil Moisture (surface to root-zone)	Soil moisture profile saturation, while 1 km resolution is desired, 25 km is useful.	Active microwave dual-channel L- and P-band radar, VV, HH, and HV polarization at spatial resolution of 100 m to 1 km.	Active microwave would provide high spatial resolution (100-200 m) soil moisture. Revisit time of 6-12 days would be possible with a single spacecraft. Root-zone soil moisture is possible by coupling the surface observations with a land surface model.

SDC Necessity: Important
Decadal Survey Importance: Very Important

Climate Variability and Change: Seasonal to Centennial (C)

Sea Level Rise (C-1)

- Ice Sheet Mass Balance (C-1c)

Decadal Scale Global Patterns (C-7)

- Link between Natural and Anthropogenic factors (C-7b)

Arctic and Antarctica (C-8)

- Polar Amplification (C-8a)
- Link between polar variability and mid-latitude weather (C-8b)
- Sea-ice cover (C-8c)
- Permafrost Thawing (C-8f)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION C-1. How much will sea level rise, globally and regionally, over the next decade and beyond, and what will be the role of ice sheets and ocean heat storage? *See also S-3a Cryosphere Perspective*	C-1c. Determine the changes in total ice sheet mass balance to within 15 Gigatons/year over the course of a decade and the changes in surface mass balance and glacier ice discharge with the same accuracy over the entire ice sheets, continuously, for decades to come	Mean flow of fast flowing outlet glaciers, grounded and floating (>50 m/yr)	Velocity	1 x week all 10 m/yr accuracy 100 m
		Mean flow of slow flowing ice-sheet interiors (<50 m/yr)	Velocity	1 x year all 0.1 m/yr accuracy 500 m
		Mean flow of large mountain glaciers	Velocity	2 x month all 10 m/yr accuracy 50 m
		Strain rates at shear margins [grounded ice]	Velocity	1 x month select 10 m/yr precision 100 m

SDC Necessity: Most Important
Decadal Survey Importance: Most Important

Objective also addressed by Solid Earth Group

Sea Level Rise (C-1) (continued)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION C-1. How much will sea level rise, globally and regionally, over the next decade and beyond, and what will be the role of ice sheets and ocean heat storage? *See also S-3a Cryosphere Perspective*	C-1c. Determine the changes in total ice sheet mass balance to within 15 Gigatons/yr over the course of a decade and the changes in surface mass balance and glacier ice discharge with the same accuracy over the entire ice sheets, continuously, for decades to come	Strain rates associated with fracture and calving and ice mélange	Velocity	4 x daily select 10 m/yr precision 100 m
		Geometry of mélange	Imagery	4 x daily select 10 m
		Tidal flexure in the grounding zones (50 km upstream and all floating)	Differential vertical displacement	4 x daily select Weekly all 30 mm accuracy 50 m
		Basal friction inverted from temporal changes in velocity	Velocity	4 x daily select 10 m/yr accuracy 100 m
		Elevation signal of interior subglacial lake drainage and filling	Differential vertical displacement	weekly select 30 mm accuracy 50 m

SDC Necessity: Most Important
Decadal Survey Importance: Most Important

Objective also addressed by Solid Earth Group

Decadal Scale Global Patterns (C-7)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION C-7. How are decadal scale global atmospheric and ocean circulation patterns changing, and what are the effects of these changes on seasonal climate processes, extreme events, and longer term environmental change?	C-7b. Quantify the linkage between natural (e.g., volcanic) and anthropogenic (greenhouse gases, aerosols, land-use) forcings and oscillations in the climate system (e.g., MJO, NAO, ENSO, QBO). Reduce the uncertainty by a factor of 2. Confidence levels desired: 67%	The relevance of this objective to SDC in the DS is rather vague.			

SDC Necessity: Important
Decadal Survey Importance: Important

Polar Amplification (C-8)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION C-8. What will be the consequences of amplified climate change already observed in the Arctic and projected for Antarctica on global trends of sea level rise, atmospheric circulation, extreme weather events, global ocean circulation, and carbon fluxes?	C-8a. Improve our understanding of the drivers behind polar amplification by quantifying the relative impact of snow/ice-albedo feedback versus changes in atmospheric and oceanic circulation, water vapor, and lapse rate feedback. C-8b. Improve understanding of high-latitude variability and midlatitude weather linkages C-8c. Improve regional-scale seasonal to decadal predictability of Arctic and Antarctic sea-ice cover, including sea-ice fraction (within 5%), ice thickness (within 20 cm), location of the ice edge (within 1 km), timing of ice retreat and ice advance (within 5 days).	Circumpolar fine scale sea ice motion & deformation (C-8a, C-8b, and C-8c)	Ice Motion	1 km, daily, 100 m/day both poles, sustained, >85N & to 78S
		Sea ice ridge and lead evolution, polynya formation, brine formation, and heat flux (C-8a, C-8b, and C-8c)	Ice Motion	500m, 4-6 times daily, 10 m/day [relative], both hemispheres, spring & winter
		Marginal/coastal sea ice zone mechanics and fluxes (C-8a, C-8b, and C-8c)	Ice Motion	100 m, 4-6 times daily, 10 m/day [relative], both hemispheres, spring & summer
		Sea ice formation and distribution (C-8a, C-8b, and C-8c)	Imagery of ice concentration, floe size, and surface roughness	10m – 100m, daily, both hemispheres, continuous

SDC Necessity: Very Important
Decadal Survey Importance: Very Important

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION C-8. What will be the consequences of amplified climate change already observed in the Arctic and projected for Antarctica on global trends of sea level rise, atmospheric circulation, extreme weather events, global ocean circulation, and carbon fluxes?	C-8f. Determine how permafrost-thaw driven land cover changes affect turbulent heat fluxes, above and below ground carbon pools, resulting greenhouse gas fluxes (carbon dioxide, methane) in the Arctic, as well as their impact on Arctic amplification.	Freeze-thaw state	Weekly, at 100m horizontal and 5-10 cm vertical resolution	Passive microwave radiometers, scatterometers, SAR; InSAR, C + L-band SAR; Tomographic SAR; Airborne EM; GPR; SMAP	PoR-12 (PALSAR), PoR-12 (Sentinel-1), PoR-23 (SMAP)
		Active layer thickness	Bi-weekly (except in winter, when no measurement is needed) at 100m horizontal and 5 cm vertical resolution	AirMOSS (P-band SAR); UAVSAR (L-band InSAR); Airborne-EM; OIB low-frequency radars; ground based (or airborne) GPR	PoR-12 (L-band PALSAR), POR-12 (NISAR)
		Lake and wetland fraction	Bi-Monthly at 100-250m	Optical instruments (e.g. MODIS, Landsat, SPOT, Sentinel-2), active SAR instruments (C+L bands)	PoR-12 (PALSAR), PoR-12 (Sentinel-1), PoR-9 (Landsat), PoR-9 (Sentinel-2), PoR-27 (SWOT), PoR-21 (MODIS)
		Snow water equivalent	Daily at 1km, within 1 cm SWE	Combination of sensors: e.g., laser altimetry, polarimetric imaging radar, microwave imaging radar, radiometers	PoR-23 (AMSR-2), PoR-23 (SMOS)
		Surface elevation	Annually at 50m resolution, within 2 cm uncertainty	Active SAR instruments (Interferometry), LIDAR; US L-band SAR; DLR Tandem-X and Tandem-L; ICESat-ATLAS	PoR-12 (L-band PALSAR), PoR-12 (S-band NISAR), PoR-12 (C-band Sentinel-1), PoR-14 (ICESat-ATLAS)

SDC Necessity: Most Important
Decadal Survey Importance: Important

Earth Surface and Interior: Dynamics and Hazards (S)

Geological Hazards (S-1)

Societal Impact (S-2)

Sea Level (S-3)

Landscape Change (S-4)

Energy Flow (S-5)

Water Flow (S-6)

Discovery & Management (S-7)

Earth Surface and Interior: Dynamics and Hazards (S)

Geological Hazards (S-1)

- Volcanic Deformation (S-1a)
- Tectonically Active Areas (S-1b)
- Landslides (S-1c)

Societal Impact (S-2)

- Response & Mitigation (S-2a)
- Assessment of Volcanic Products (S-2b)
- Landslides (S-2c)

Sea Level (S-3)

- Sea Level Change (S-3a)
- Vertical Motion of Coastal Land (S-3b)

Earth Surface and Interior: Dynamics and Hazards (S)

Landscape Change (S-4)

- Reshaping Earth's Surface (S-4a)
- Content of Near Surface Materials (S-4b)

Energy Flow (S-5)

- Effect of Convection (S-5a)

Water Flow (S-6)

- Confined Aquifers (S-6a)
- Groundwater System (S-6b)
- Shallow Aquifers (S-6c)
- Impact of Human/Natural Activities on Earthquakes (S-6d)

Discovery and Management (S-7)

- Energy, Mineral, Agricultural, & Natural Resources (S-7a)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-1. How can large-scale geological hazards be accurately forecast in a socially relevant timeframe?	S-1a. Measure the pre-, syn-, and post eruption surface deformation and products of the Earth's entire active land volcano inventory at a time scale of days weeks.	Land surface deformation	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 kms and a precision of 1 mm at a sampling frequency related to the volcanic activity. Regionally-sampled global coverage.	L- or S-band InSAR with Ionospheric correction	Wavelength – L or S band Spatial resolution: 10 m Length scale: 30-50 km – 100s of kms Temporal resolution: daily with ability to task measurements at sub-daily frequency.

SDC Necessity: Most Important
Decadal Survey Importance: Most Important

Objective also addressed by GeoHazards Group

Geological Hazards (S-1) (GeoHazards Perspective)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-1. How can large-scale geological hazards be accurately forecast in a socially relevant timeframe?	S-1a. Measure the pre-, syn-, and post eruption surface deformation and products of the Earth's entire active land volcano inventory at a time scale of days weeks.	Land surface deformation	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 kms and a precision of 1 mm at a sampling frequency related to the volcanic activity. Regionally-sampled global coverage.	L- or S-band InSAR with Ionospheric correction	Monitoring: Spatial resolution: 10 - 100 m Sampling frequency: weekly Product latency: <2 days Accuracy: < 1 cm per observation (local, relative) Crisis: Determined by threat of eruption, flow. Spatial resolution: 10 m Sampling frequency: daily Product latency: <3 hours Accuracy: < 5 cm per observation (local, relative) Post-Event (few months) Spatial resolution: 10 m Sampling frequency: 2-3 times per week Product latency: <24 hours Accuracy: < 5 cm per observation (local, relative)

SDC Necessity: Very Important
Decadal Survey Importance: Most Important

Objective also addressed by Solid Earth Group

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-1. How can large-scale geological hazards be accurately forecast in a socially relevant timeframe?	S-1b. Measure and forecast interseismic, preseismic, coseismic, and postseismic activity over tectonically active areas on time scales ranging from hours to decades.	Land surface deformation	At least 2 components of land surface deformation 10 m to 100s of kms of resolution and precision of 1-10 mm at a sampling frequency related to seismic/tectonic activity. Ideally, resolution of 1 mm/week. Need more than 10 years of observations to measure interseismic deformation	L- or S-band InSAR with ionospheric correction	Spatial resolution: 10 m for near fault processes, but 50 m would be sufficient for most fault processes Measurement in 3D is critical for resolving overlapping processes Temporal resolution: Daily for post-seismic, short-term creep events. Higher temporal resolution is expected to be more important than higher spatial resolution for advancing science.

SDC Necessity: Most Important
Decadal Survey Importance: Most Important

Objective also addressed by GeoHazards Group

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-1. How can large-scale geological hazards be accurately forecast in a socially relevant timeframe?	S-1b. Measure and forecast interseismic, preseismic, coseismic, and postseismic activity over tectonically active areas on time scales ranging from hours to decades.	Land surface deformation	At least 2 components of land surface deformation 10 m to 100s of kms resolution and precision of 1-10 mm at a sampling frequency related to seismic/tectonic activity. Ideally, resolution of 1 mm/week. Need more than 10 year of observations to measure interseismic deformation	L- or S-band InSAR with ionospheric correction	Monitoring: NISAR-like capabilities. Crisis: at occurrence of an earthquake. Coseismic stage is <14 days post-event. Spatial resolution: 10 m (3m for improved damage proxy map) Sampling frequency: daily (data from constellation of different instruments are usable) Product latency: <3 hours Accuracy: 1 cm per observation (local, relative) Post stage can be a few months. Need to capture and sample between any major aftershocks. Spatial resolution: 10-30 m Sampling frequency: daily Product latency: <12 hours Accuracy: 1 cm per observation (local, relative)

SDC Necessity: Most Important
Decadal Survey Importance: Most Important

Objective also addressed by Solid Earth Group

Geological Hazards (S-1) (Solid Earth Perspective)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-1. How can large-scale geological hazards be accurately forecast in a socially relevant timeframe?	S-1c. Forecast and monitor landslides, especially those near population centers.	Land surface deformation	At least 2 components of land surface deformation at <50 m spatial resolution and 1mm/yr at a temporal frequency <seasonal (InSAR and GPS/GNSS)	L- or S-band InSAR	Wavelength: Need to preserve coherence - drives need for longer wavelength in order to get good coherence in forested regions. Temporal frequency: from sub-daily to monthly Spatial resolution: at least 10 m observation resolution Baseline: 3 components are important estimating landslide thickness with rheological models.

SDC Necessity: Most Important
Decadal Survey Importance: Very Important

Objective also addressed by GeoHazards Group

Geological Hazards (S-1) (GeoHazards Perspective)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-1. How can large-scale geological hazards be accurately forecast in a socially relevant timeframe?	S-1c. Forecast and monitor landslides, especially those near population centers.	Land surface deformation	At least 2 components of land surface deformation at <50 m spatial resolution and 1mm/yr at a temporal frequency <seasonal (InSAR and GPS/GNSS)	L- or S-band InSAR	Monitoring: Spatial resolution: 10 m Sampling frequency: 6 days Product latency: < 2 days Accuracy: 1 mm/yr (achieved with 10-yr time series) Crisis: Crisis stage will generally start with prediction of localized heavy precipitation, ~2 days before starts, and will last ~3 days post-rain. Crisis stage also initiated by proximal earthquake. Spatial resolution: 10 m Sampling frequency: 6-12 hours Product latency: <3 hours Accuracy: 1 cm/day (local, relative) Post: Post stage duration depends on rain and motion rates during crisis stage. Spatial resolution: 10 m Sampling frequency: daily Product latency: <12 hours Accuracy: 1 cm/day (local, relative)

SDC Necessity: Important
Decadal Survey Importance: Very Important

Objective also addressed by Solid Earth Group

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-2. How do geological disasters directly impact the Earth system and society following an event?	S-2a. Rapidly capture the transient processes following disasters for improved predictive modeling as well as response and mitigation through optimal re-tasking and analysis of space data	Provide rapid deformation map acquisitions and interconnectivity to other sensors	At least 2 components of land surface deformation over 10 m to 100s of kms length scales at 10 mm precision and ASAP after the event. Adequate resolution of 1 cm/week for afterslip applications	InSAR	

SDC Necessity: Most Important
Decadal Survey Importance: Most Important

Objective also addressed by GeoHazards Group

Societal Impact (S-2) (GeoHazards Perspective)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-2. How do geological disasters directly impact the Earth system and society following an event?	S-2a. Rapidly capture the transient processes following disasters for improved predictive modeling as well as response and mitigation through optimal re-tasking and analysis of space data	Provide rapid deformation map acquisitions and interconnectivity to other sensors	At least 2 components of land surface deformation over 10 m to 100s of kms length scales at 10 mm precision and ASAP after the event. Adequate resolution of 1 cm/week for afterslip applications	InSAR	From H-4/S-1: Monitoring: Spatial resolution: 10 - 100 m Sampling frequency: weekly Product latency: <2 days Accuracy: < 1 cm per observation (local, relative) Crisis: Determined by threat of eruption, flow. Spatial resolution: 10 m Sampling frequency: daily Product latency: <3 hours Accuracy: < 5 cm per observation (local, relative) Post-Event (few months) Spatial resolution: 10 m Sampling frequency: 2-3 times per week Product latency: <24 hours Accuracy: < 5 cm per observation (local, relative)

SDC Necessity: Most Important
Decadal Survey Importance: Most Important

Objective also addressed by Solid Earth Group

Societal Impact (S-2) (Solid Earth Perspective)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-2. How do geological disasters directly impact the Earth system and society following an event?	S-2b. Assess surface deformation (<10 mm), extent of surface change (<100 m spatial resolution) and atmospheric contamination, and the composition and temperature of volcanic products following a volcanic eruption (hourly to daily temporal sampling)	Land surface deformation	At least 2 components of land surface deformation and surface fracturing over length scales ranging from 10 m to 100s of kms and temporal resolution of 1 mm yr-1 at a sampling frequency related to the volcanic activity everywhere.	L- or S-band InSAR with Ionospheric correction	Wavelength – L or S band Spatial resolution: 10 m Length scale: 30-50 km – 100s of kms Temporal resolution: daily with ability to task measurements at sub-daily frequency.

SDC Necessity: Most Important
Decadal Survey Importance: Very Important

Objective also addressed by GeoHazards Group

Societal Impact (S-2) (GeoHazards Perspective)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-2. How do geological disasters directly impact the Earth system and society following an event?	S-2b. Assess surface deformation (<10 mm), extent of surface change (<100 m spatial resolution) and atmospheric contamination, and the composition and temperature of volcanic products following a volcanic eruption (hourly to daily temporal sampling)	Land surface deformation	At least 2 components of land surface deformation and surface fracturing over length scales ranging from 10 m to 100s of kms and temporal resolution of 1 mm yr-1 at a sampling frequency related to the volcanic activity everywhere.	L- or S-band InSAR with Ionospheric correction	From S-1: Monitoring: Spatial resolution: 10 - 100 m Sampling frequency: weekly Product latency: <2 days Accuracy: < 1 cm per observation (local, relative) Crisis: Determined by threat of eruption, flow. Spatial resolution: 10 m Sampling frequency: daily Product latency: <3 hours Accuracy: < 5 cm per observation (local, relative) Post-Event (few months) Spatial resolution: 10 m Sampling frequency: 2-3 times per week Product latency: <24 hours Accuracy: < 5 cm per observation (local, relative)

SDC Necessity: Most Important
Decadal Survey Importance: Very Important

Objective also addressed by Solid Earth Group

Societal Impact (S-2) (Solid Earth Perspective)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-2. How do geological disasters directly impact the Earth system and society following an event?	S-2c. Assess co- and postseismic ground deformation (spatial resolution of 100 m and an accuracy of 10 mm) and damage to infrastructure following an earthquake.	Land surface deformation	At least 2 components of land surface deformation at 100 m spatial resolution and 1 mm yr-1 at a temporal frequency related to the tectonic activity. Need more than 10 years of interseismic observations and 5 years of postseismic observations	L- or S-band InSAR with ionospheric correction	Spatial resolution: 10 m for near fault processes, but 50 m would be sufficient for most fault processes Measurement in 3D is critical for resolving overlapping processes Temporal resolution: Daily for post-seismic, short-term creep events. Higher temporal resolution is expected to be more important than higher spatial resolution for advancing science.

SDC Necessity: Most Important
Decadal Survey Importance: Very Important

Objective also addressed by GeoHazards Group

Societal Impact (S-2) (GeoHazards Perspective)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-2. How do geological disasters directly impact the Earth system and society following an event?	S-2c. Assess co- and postseismic ground deformation (spatial resolution of 100 m and an accuracy of 10 mm) and damage to infrastructure following an earthquake.	Land surface deformation	At least 2 components of land surface deformation at 100 m spatial resolution and 1 mm yr-1 at a temporal frequency related to the tectonic activity. Need more than 10 years of interseismic observations and 5 years of postseismic observations	L- or S-band InSAR with ionospheric correction	From S-1: Monitoring: Spatial resolution: 10 - 100 m Sampling frequency: weekly Product latency: <2 days Accuracy: < 1 cm per observation (local, relative) Crisis: Determined by threat of eruption, flow. Spatial resolution: 10 m Sampling frequency: daily Product latency: <3 hours Accuracy: < 5 cm per observation (local, relative) Post-Event (few months) Spatial resolution: 10 m Sampling frequency: 2-3 times per week Product latency: <24 hours Accuracy: < 5 cm per observation (local, relative)

SDC Necessity: Most Important
Decadal Survey Importance: Very Important

Objective also addressed by Solid Earth Group

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-3. How will local sea level change along coastlines around the world in the next decade to century?	S-3a. Quantify the rates of sea level change and its driving processes at global, regional, and local scales, with uncertainty < 0.1 mm yr-1 for global mean sea-level equivalent and <0.5 mm yr-1 sea-level equivalent at resolution of 10 km.	3D surface deformation vectors on ice sheets	Monthly, cm yr-1 accuracy, 100 m resolution and better than seasonal sampling	InSAR	PoR-12 (NISAR)
		Horizontal Ice velocity	Monthly or less, uncertainty <10 cm yr-1 over areas of 100 km^2	InSAR	PoR-12 (NISAR)

SDC Necessity: Most Important
Decadal Survey Importance: Most Important

Objective also addressed by Cryosphere Group

Sea Level (S-3) (Cryosphere Perspective)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-3. How will local sea level change along coastlines around the world in the next decade to century? *See also C-1c*	S-3a. Quantify the rates of sea level change and its driving processes at global, regional, and local scales, with uncertainty < 0.1 mm yr-1 for global mean sea-level equivalent and <0.5 mm yr-1 sea-level equivalent at resolution of 10 km.	Mean flow of fast flowing outlet glaciers, grounded and floating (>50 m/yr)	Velocity	1 x week all 10 m/yr accuracy 100 m
		Mean flow of slow flowing ice-sheet interiors (<50 m/yr)	Velocity	1 x year all 0.1 m/yr accuracy 500 m
		Mean flow of large mountain glaciers	Velocity	2 x month all 10 m/yr accuracy 50 m
		Strain rates at shear margins (grounded ice)	Velocity	1 x month select 10 m/yr precision 100 m
		Strain rates associated with fracture and calving and ice mélange	Velocity	4 x daily select 10 m/yr precision 100 m
		Geometry of ice mélange	Imagery	4 x daily select 10 m
		Tidal flexure in the grounding zones (50 km upstream and all floating)	Differential vertical displacement	4 x daily select Weekly all 30 mm accuracy 50 m
		Basal friction inverted from temporal changes in velocity	Velocity	4 x daily select 10 m/yr accuracy 100 m
		Elevation signal of Interior subglacial lake drainage and filling	Differential vertical displacement	Weekly select 30 mm accuracy 50 m

SDC Necessity: Most Important
Decadal Survey Importance: Most Important

Objective also addressed by Solid Earth Group

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-3. How will local sea level change along coastlines around the world in the next decade to century?	S-3b. Determine vertical motion of land along coastlines at uncertainty <1 mm yr.	Land surface deformation (both anthropogenic and tectonic/geologic deformation)	5-10 mm vertical precision, <50 m horizontal, weekly	InSAR	Wavelength: One of the biggest challenges is connecting different coastal wetlands together - longer wavelengths can help a lot with the measurement. Spatial resolution: anthropogenic changes vary on 100's m spatial scale. 50 m would be needed to do spatial averaging. Need for long time series/continuity. Temporal resolution: want to be able to measure seasonal changes in vertical velocity at cm/yr accuracy. For long term rates, decadal scale velocities need mm/yr, cm/decade.

SDC Necessity: Most Important
Decadal Survey Importance: Most Important

Objective also addressed by GeoHazards Group

Sea Level (S-3) (GeoHazards Perspective)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-3. How will local sea level change along coastlines around the world in the next decade to century?	S-3b. Determine vertical motion of land along coastlines at uncertainty <1 mm/yr.	Land surface deformation	5-10 mm vertical precision, <50 m horizontal, weekly	InSAR	Spatial resolution: 50 m Sampling frequency: 6-12 days (6 day better) Product latency: <2 days (NISAR-like) Accuracy: Achieve 1 mm/yr with 10-year time series.

SDC Necessity: Most Important
Decadal Survey Importance: Most Important

Objective also addressed by Solid Earth Group

Landscape Change (S-4)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-4. What processes and interactions determine the rates of landscape change?	S-4a. Quantify global, decadal landscape change produced by abrupt events and by continuous reshaping of Earth's surface due to surface processes, tectonics, and societal activity.	Land surface deformation	5-10 mm vertical precision, 10 m or <50 m horizontal, weekly	L- or S-band InSAR, [UAVSAR].	High spatial resolution - 10 meter range - would be helpful.
		Soil Moisture	<50 m horizontal, weekly	Radar reflectivity	Higher spatial resolution would likely more important than higher temporal resolution. Soil moisture could be highly valuable here.

SDC Necessity: Very Important
Decadal Survey Importance: Most Important

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-4. What processes and interactions determine the rates of landscape change?	S-4b. Quantify weather events, surface hydrology, and changes in ice/water content of near surface materials that produce landscape change.	Reflectance for freeze/thaw spatial and temporal distribution Reflectance for snow depth / snow water equivalent	< 50 m horizontal, weekly SWE at ~100 m resolution suitable for SWE values to 2.5 m??.	Radar reflectivity Ka band radar or laser altimeter (depth) and SAR (density) InSAR	PoR-12 (NISAR) PoR-17 (KaRIN, SWOT) PoR-12 (NISAR)

SDC Necessity: Most Important
Decadal Survey Importance: Important

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-5. How does energy flow from the core to the Earth's surface?	S-5a. Determine the effects of convection within the Earth's interior, specifically the dynamics of the Earth's core and its changing magnetic field and the interaction between mantle convection and plate motions.	Determine plate motions and deformation and track the evolution of plate boundaries	SAR interferometry, 10 mm vertical, 100m mm horizontal	L-band InSAR with ionospheric correction	Steady velocity measurement of convection scale features - vertical measurement, epeirogenic uplift. Would need to remove tropospheric and ionospheric noise, have very low noise, cm orbit determination. Global Coverage that will enable a composite image taken over months to years. InSAR on a local/regional scale would also help in identifying GPS sites that are being affected by regional deformation.

SDC Necessity: Important
Decadal Survey Importance: Very Important

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-6. How much water is traveling deep underground and how does it affect geological processes and water supplies?	S-6a. Determine the fluid pressures, storage, and flow in confined aquifers at spatial resolution of 100 m and pressure of 1 kPa (0.1 m head).	Land surface deformation	For seasonal variations: 1 cm/yr measured weekly at 10 m spatial sampling (which allows stacking for sub cm secular trends)	L- or S-band InSAR	Spatial resolution: 100 m (after multi-looking, so would want 10 m 'raw' resolution) Temporal resolution: daily (for resolving confined/unconfined aquifers), weekly (for coherence over agricultural areas, common for aquifers). 3D measurements. Regionally-sampled global coverage Continuity between missions for long time series measurements is important.

SDC Necessity: Most Important
Decadal Survey Importance: Very Important

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-6. How much water is traveling deep underground and how does it affect geological processes and water supplies?	S-6b. Measure all significant fluxes in and out of the groundwater system across the recharge area.	Deformation from fluid fluxes	Spatiotemporal distribution of subsidence/uplift at 3 mm vertical per year, 5 m horizontal, weekly. Coverage overactive reservoirs.	L- or S-band InSAR	Spatial resolution: 100 m (after multi-looking, so would want 10 m 'raw' resolution) Temporal resolution: daily (for resolving confined/unconfined aquifers), weekly (for coherence over agricultural areas, common for aquifers). 3D measurements. Regionally-sampled global coverage Continuity between missions for long time series measurements is important.
		Land surface deformation	Spatiotemporal distribution of subsidence/uplift at 1 cm vertical, 5 m horizontal, weekly. Coverage over managed watersheds, other watersheds of interest	L- or S-band InSAR	

SDC Necessity: Most Important
Decadal Survey Importance: Important

Water Flow (S-6)

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-6. How much water is traveling deep underground and how does it affect geological processes and water supplies?	S-6c. Determine the transport and storage properties in situ within a factor of 3 for shallow aquifers and an order of magnitude for deeper systems.	Deformation from fluid fluxes	Spatiotemporal distribution of subsidence/uplift at 3 mm/yr vertical, 5 m horizontal, weekly. Coverage overactive reservoirs.	L- or S-band InSAR	PoR-12 (NISAR)

SDC Necessity: Most Important
Decadal Survey Importance: Important

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-6. How much water is traveling deep underground and how does it affect geological processes and water supplies?	S-6d. Determine the impact of water-related human activities and natural water flow on earthquakes.	Land surface deformation	Spatiotemporal distribution of subsidence/uplift at 3 mm/yr vertical, 5 m horizontal, weekly	L- or S-band InSAR	PoR-12 (NISAR)

SDC Necessity: Very Important
Decadal Survey Importance: Important

Societal or Science Question/Goal	Earth Science/Application Objective	Geophysical Observable	Measurement Parameters	Methods	Desired Capabilities (λ, Δx, Δy, Δz, Δt, latency)
QUESTION S-7. How do we improve discovery and management of energy, mineral, and soil resources?	S-7a. Map topography, surface mineralogical composition/distribution, thermal properties, soil properties/water content, and solar irradiance for improved development and management of energy, mineral, agricultural, and natural resources.	Land surface deformation	Spatiotemporal distribution of subsidence/uplift at 1 cm vertical, 5 m horizontal, weekly	L- or S-band InSAR with ionospheric correction	PoR-12 (NISAR)

SDC Necessity: Important
Decadal Survey Importance: Important

Hydrology + Ecosystems Groups

H-2c – Hydrology Link, Aggregate Table Hydrology Link, Aggregate Table Ecosystems Link

H-4a – Hydrology Link, Aggregate Table Hydrology Link, Aggregate Table Ecosystems Link

Solid Earth + GeoHazards Groups

S-1a – Solid Earth Link, GeoHazards Link, Aggregate Table Link

S-1b – Solid Earth Link, GeoHazards Link, Aggregate Table Link

S-1c – Solid Earth Link, GeoHazards Link, Aggregate Table Link

S-2a – Solid Earth Link, GeoHazards Link, Aggregate Table Link

S-2b – Solid Earth Link, GeoHazards Link, Aggregate Table Link

S-2c – Solid Earth Link, GeoHazards Link, Aggregate Table Link

S-3b – Solid Earth Link, GeoHazards Link, Aggregate Table Link

Solid Earth + Cryosphere Groups

S-3a – Solid Earth Link, Cryosphere Link, Aggregate Table Solid Earth Link, Aggregate Table Cryosphere Link