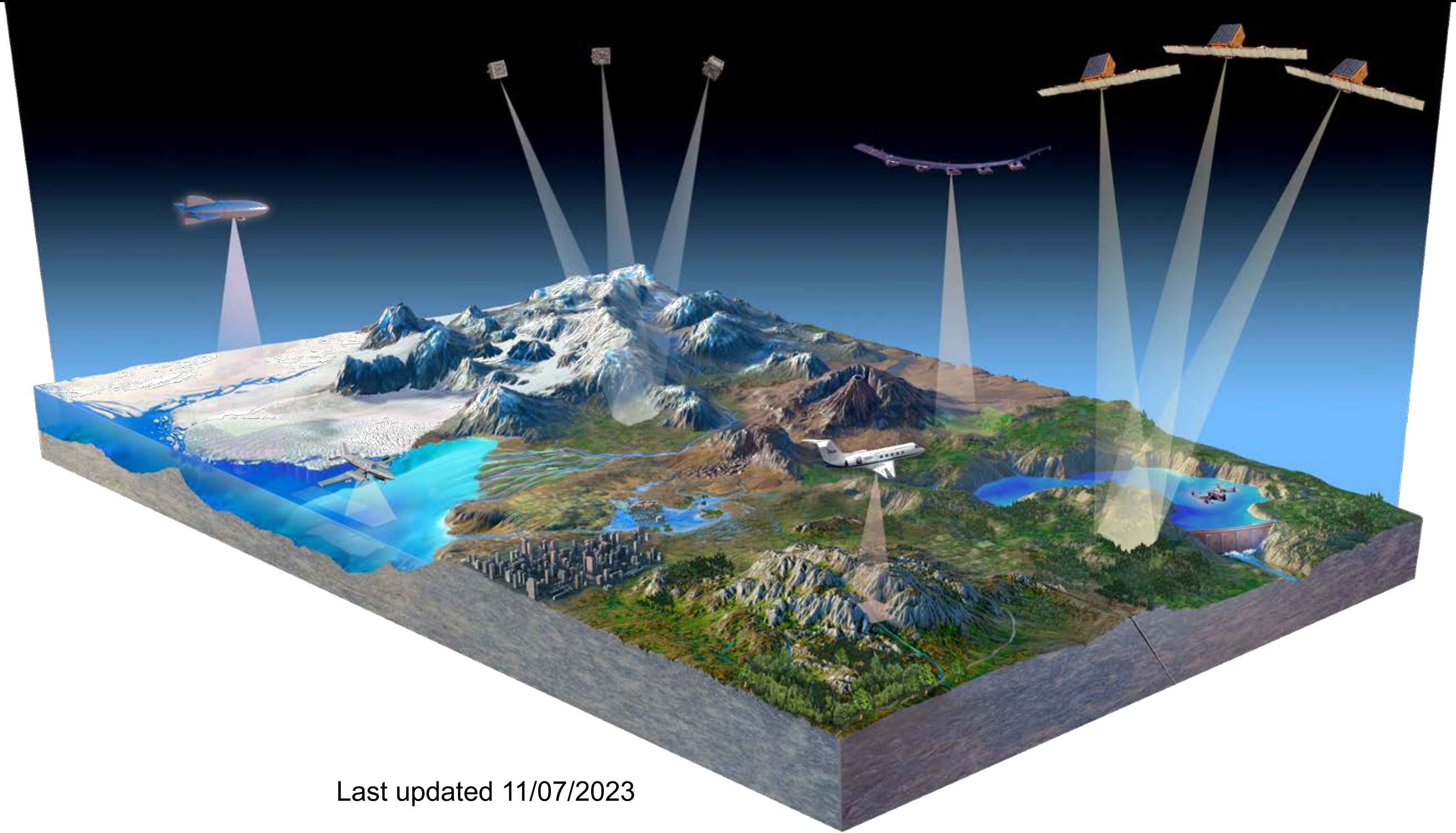
NASA's Surface Topography and Vegetation Study

Hydrology



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STV Hydrology Group

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STV Community Hybrid meeting

Hotel Dena in Pasadena, California November 14-15, 2023.

This meeting provides an opportunity for the STV team to draw on the diversity of expertise, experience, and backgrounds from the broader community.

Hydrology Breakout Meeting Goal:
Refine the science questions and compelling applications for STV, establish observing priorities, identify measurement gaps, and discuss technology maturation.

Develop Science activities designed to advance and accelerate the readiness of the Surface Topography and Vegetation (STV) Targeted Observable (TO).

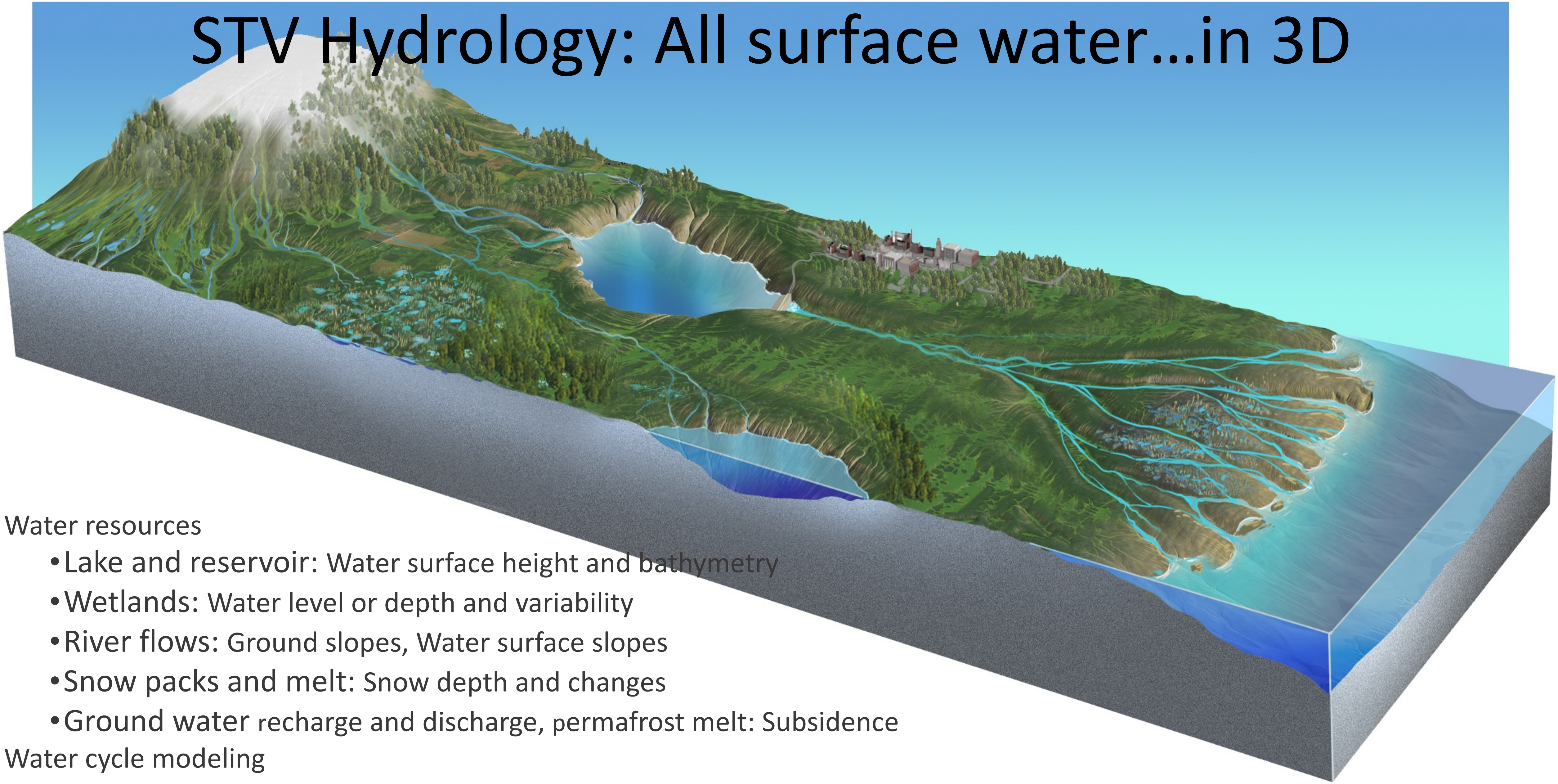
STV Hydrology Question

How will water availability and flow change with climate and increasingly dynamic landscapes?

Measurement Challenge

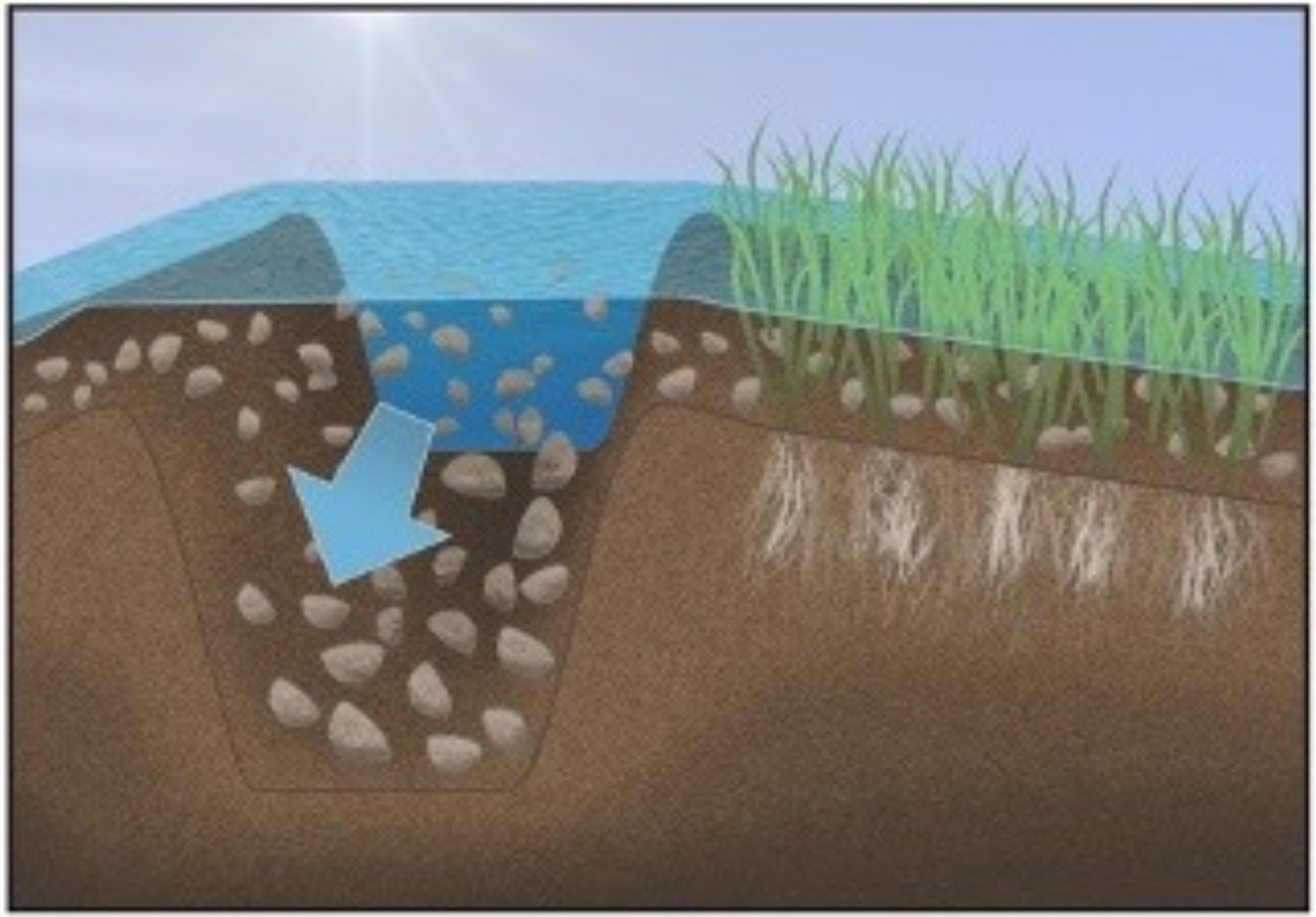
Reconcile measurement needs from an interdisciplinary community interested in hydrology and applicable to a diversity of landscapes.

STV Hydrology: All surface water…in 3D



- Water resources
    - Lake and reservoir: Water surface height and bathymetry
    - Wetlands: Water level or depth and variability
    - River flows: Ground slopes, Water surface slopes
    - Snow packs and melt: Snow depth and changes
    - Ground water recharge and discharge, permafrost melt: Subsidence
- Water cycle modeling
- Flooding and inundation modeling
- Wetland processes and management

STV Hydrology needs 3 elevations



Vegetation CHM = DSM-DTM

Water level WSE = DSM-DTM (or SWE)

Ground elevation DTM

A variety of remote sensing technologies are available to address STV-Hydrology measurement needs

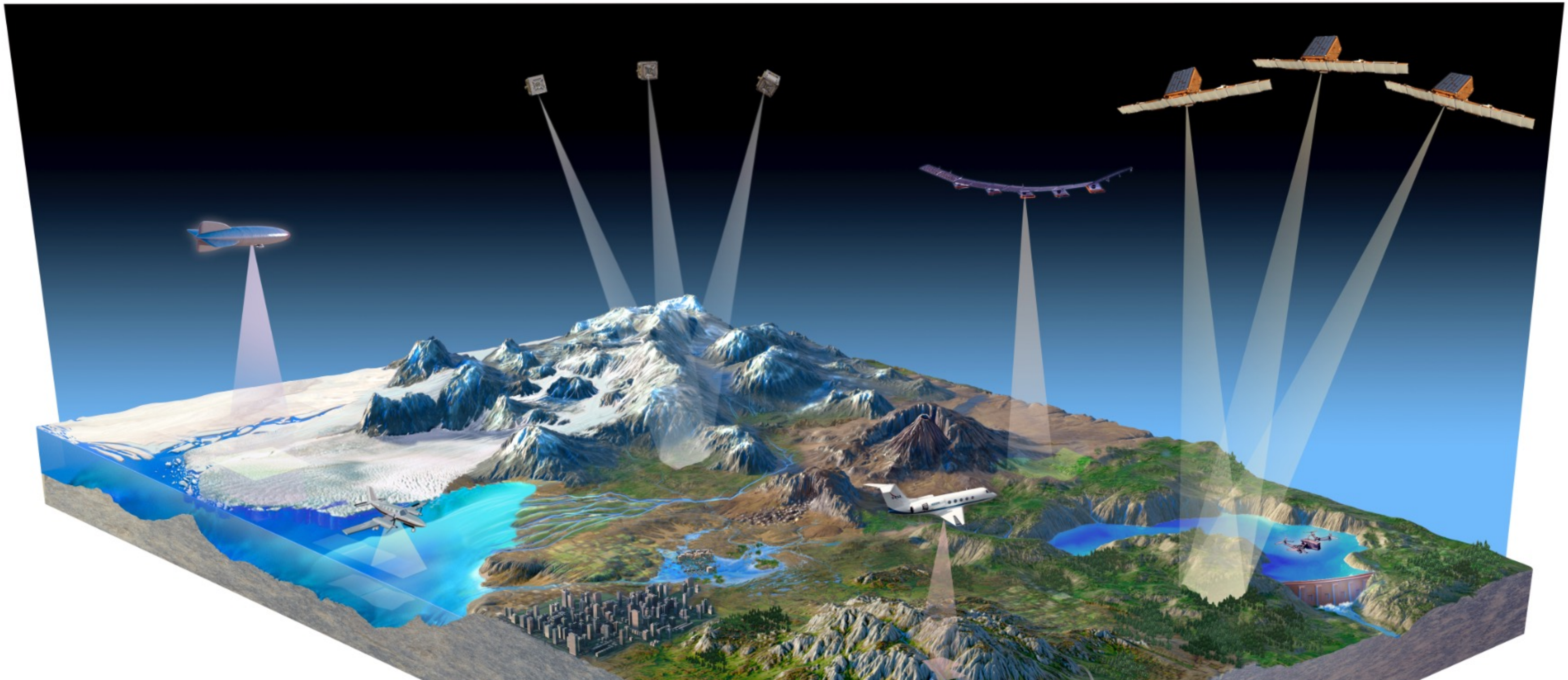


Table 8-4. Goals and objectives serving the interests of the hydrological science community.

Goal	Objectives	STV Observable
How is the water cycle and fresh water availability changing with climate change, land cover change and water diversion structures?	Develop and evaluate an integrated Earth system analysis with sufficient observational input to accurately quantify the components of the water and energy cycles and their interactions, and to close the water balance from headwater catchments to continental-scale river basins.	Surface topo Bathymetry Veg. structure Snow depth
	Quantify the impact of land cover change, modification and soil disturbances on water, carbon, sediment and energy fluxes at/below/above the land surface.	Surface topo Bathymetry
	Quantify rates of snow accumulation, snowmelt, ice melt, and sublimation from snow and ice worldwide.	Surface topo Bathymetry Snow depth
	Quantify lake and reservoir water balances, and their responses to climate extremes and human activities?	Surface topo Bathymetry
How do changes in the water cycle impact local and regional freshwater availability affect biogeochemical processes, ecosystems, and the services these provide?	Quantify lake and reservoir water balances, and their responses to climate extremes and human activities?	Surface topo Bathymetry
	Quantify the flows of energy, water, carbon, nutrients, etc, sustaining the life cycle of terrestrial and marine ecosystems (e.g. wetlands) and partitioning into functional types.	Surface topo Bathymetry Veg. structure
	Quantify how changes in land use, land cover, and water use related to agricultural activities, food production, and forest management affect water quantity and quality of above and below groundwater.	Surface topo Bathymetry Veg. structure
	Quantify rates of snow accumulation, snowmelt, ice melt, from snow and ice within catchments.	Surface topo Snow depth
How does the water cycle interact with other Earth System processes to change the predictability and impacts of hazardous events and hazard-chains?	Develop and evaluate an integrated Earth system analysis with sufficient observational input to accurately quantify the components of the water and energy cycles and their interactions, and to close the water balance from headwater catchments to continental-scale river basins.	Surface topo Bathymetry Veg. structure Snow depth
How will cold region runoff, surface water bodies and groundwater respond to climate change and permafrost thaw?	Develop and evaluate an integrated Earth system analysis with sufficient observational input to accurately quantify the components (e.g. temperature, snow, surface water, vegetation structure, hydrologic connectivity), of the water and energy cycles and their interactions.	Surface topo Bathymetry Veg. structure Snow depth

Table 5-5. Hydrology knowledge gaps and potential gap-filling activities. Associated SATM product parameters are in parenthesis. For associated SATM product parameters C = coverage, H = horizontal resolution, VS = vegetation 3D structure vertical resolution, VA = vertical accuracy, G = geolocation accuracy, B = bathymetry depth, S = slope accuracy, L = latency, RF = repeat frequency, RD = repeat duration, R = rate of change accuracy.

Hydrology gap description	Potential gap filling activities
[Land cover] Understanding and quantify how the landscape topographic features (e.g. bed roughness, mining, levees, roads) and vegetation structure (e.g., agriculture, wetlands, forests) impact various components of the water cycles such as river discharge, underground recharge and evapotranspiration. Can STV remote sensing provide adequate performance? (H, VS, VA, G, R)	• Perform a model sensitivity analysis to parameters representing catchment with a variety geo- hydro- and eco-morphological conditions. • Develop OSSEs, based on above models, to simulate remote sensing observations and assess STV retrieval algorithms for a variety of sensor configurations. • Use existing airborne and/or spaceborne remote sensing instruments to assess current remote sensing performance and achievable accuracy, and compare performance against above sensitivity analysis for representative geomorphological, hydrological=, and vegetation conditions.
[Weltands] Understanding the sensitivity of wetland health, structure and productivity on water surface height and hydroperiod? Can remote sensing provide adequate performance for various geo-hydro- and eco- morphological conditions? (H, VS, VA, G, R)	• Using hydrodynamic models, perform sensitivity analysis on various model parameters in representative wetlands with various geo- hydro- and eco- morphological conditions = that includes interactions/connectivity with these components. • Develop OSSEs, based on above models, to simulate remote sensing observations and assess performance of STV retrieval algorithms. • Use airborne and/or spaceborne remote sensing instruments to assess current remote sensing performance and achievable accuracy, against above sensitivity analysis. • Assess different algorithms to processing remote sensing data to improve accuracy and potentially mitigate shortcoming of current or near-term remote sensing capabilities, over a variety of eco- and hydro- and geo-morphological conditions.
[Snow] Understanding the spatial and temporal scales of geophysical and climatic processes acting on snow packs and the availability of freshwater availability. (H, VS, VA, G, R)	• Determine the level of quality of data product needed (e.g. spatial resolution, temporal sampling and vertical accuracy) to quantify the impact of climate change on snow packs and associated fresh water availability. • Use existing OSSE or develop new OSSEs that can be used to simulate remote sensing observations and retrieval of snow depth in various geomorphological conditions and characteristics of vegetation cover. • Use airborne and/or spaceborne remote sensing instruments to evaluate, in response to above data quality, current remote sensing performance and achievable accuracy given a variety of . • Assess different algorithms to processing remote sensing data to improve accuracy and potentially mitigate shortcoming of current or near-term remote sensing capabilities, over a variety of geo-morphological conditions and characteristics of vegetation cover.

Table 5-5 (continued). Hydrology knowledge gaps and potential gap-filling activities. Associated SATM product parameters are in parenthesis. For associated SATM product parameters C = coverage, H = horizontal resolution, VS = vegetation 3D structure vertical resolution, VA = vertical accuracy, G = geolocation accuracy, B = bathymetry depth, S = slope accuracy, L = latency, RF = repeat frequency, RD = repeat duration, R = rate of change accuracy.

[Permafrost] Understanding how the hydrology of permafrost regions evolves in response to climate change, and how it shapes the landscapes. (H, VS, VA, G, R)	• Using models, perform sensitivity analysis on various model parameters in representative permafrost regions with various geo- hydro- and eco- morphological conditions. How accurately should elevation parameters be measured? • Develop OSSEs, based on above models, to simulate remote sensing observations and assess performance of STV retrieval algorithms. • Use airborne and/or spaceborne remote sensing instruments to assess current remote sensing performance and achievable accuracy, against above sensitivity analysis. • Assess different algorithms to processing remote sensing data to improve accuracy and potentially mitigate shortcoming of current or near-term remote sensing capabilities, over a variety of eco- and hydro- and geo-morphological conditions.
[Water cycle] From watersheds to the ocean, what are the lateral fluxes of water between the different components of the landscape and water cycle? (H, VS, VA, G, R)	• Using hydrodynamic models, perform sensitivity analysis on various model parameters in representative river and/or reiver networks with various geo- hydro- and eco- morphological conditions. • Develop OSSEs, based on above models, to simulate remote sensing observations and assess performance of STV retrieval algorithms in those various conditions. • Use airborne and/or spaceborne remote sensing instruments to assess current remote sensing performance and achievable accuracy, against above sensitivity analysis. • Assess different algorithms to processing remote sensing data to improve accuracy and potentially mitigate shortcoming of current or near-term remote sensing capabilities, over a variety of eco- and hydro- and geo-morphological conditions.
[Lakes and reservoirs] What is the relative impact of lakes and reservoirs on local and regional hydrology? (H, VA, G, R)	• Determine the quality of data product needed (e.g. spatial resolution, temporal sampling and vertical accuracy) to mode water balance in lakes and reservoirs. • Assess different algorithms to processing remote sensing data to improve accuracy and potentially mitigate shortcoming of current or near-term remote sensing capabilities, over a variety or seasonal and hydrological conditions.

Table 3-6. Applications in Hydrology

Goals	Objectives	Targeted Observable(s)
Flood Disaster Response	Map floodwater extent	Surface topo and Bathy
	Map the change in water level in forested and urban areas	Surface topo (& change)
Flood forecast	Forecast the flood pathway and extent from surface water runoff	Surface topo Veg Structure
	Measure the change in snow water and forecast the future snow melt	Surface topo change
Hydrological connectivity	Map runoff pathways	Surface topo
	Map channel networks	Surface topo
Water resource management	Measure aquifer drawdown and recharge, both natural and anthropogenic	Surface topo change
	Measure water stored in snow (snow extent and SWE)	Surface topo
Permafrost	Map permafrost location and extent.	Surface topo
	Map permafrost active layer thickness	Surface topo change

The STV Hydrology community identified the product needs that are similar to those of the DS with an overall median spatial resolution of 5 m and vertical accuracy of 0.1 m.

Geophysical measurements	STV Products	Resolution	Vertical Accuracy	Repeat/duration
River flows	Shallow bathymetry DTM	1	0.1	1y/5y
	Water surface height DSM	1	0.1	1d/4y
	Bank height continuous	1	0.1	1y/5y
Water volume in lakes and reservoirs	Water surface height DSM	1	1	1m/5y
	Shallow bathymetry DTM	1	0.1	1y/5y
Measure changes in hydrological framework of Permafrost	Veg Structure Height	30	1	1y/5y
	Topography DTM and change	10	0.1	10d/4y
	Shallow bathymetry DTM	10	0.1	1y/5y
	Snow depth (DSM-DTM)	10	0.1	1y/5y
	Water surface elevation DSM	1	0.2	10d/4y
Flow and hydroperiod in Wetlands	Water surface height DSM	10	0.1	7d/5y
	Shallow bathymetry DSM	5	0.1	1y/5y
	Vegetation structure Height + profile	10	0.5	1m/5y
Snow packs	Snow depth DSM-DTM	100	1	1y/5y
Watershed/basin flows	Topography DTM	3	1	1y/5y
Flood Plain Topography	Topography DTM	5	0.25	1y/5y

Hydrology-Needed Experiments

Existing and proposed

- Develop a prioritized list of targets for airborne campaigns to assess measurement capabilities ar performance for determining shallow water bathymetry, wetlands, water surface elevation.
- Identify existing tools
- Identify and compile database:
    - Airborne
        - Delta-X (Mississippi River Delta): UAVSAR-L, AirSWOT, AVIRISNG, Green bathy Lidar
        - AfriSAR campaign (Gabon): UAVSAR-L, LVIS, DLR's IFSAR X/L/P.
        - AfriSAR-2 campaign (Gabon, Ghana, Nigeria, Congo basin , Tanzania, Mozambique): UAVSAR-L/P, LVIS, DLR's IFSAR X
        - ABoVE campaign (Alaska, NWT): UAVSAR-L, AirSWOT, LVIS
        - SWOT cal/val: AirSWOT, NIR Lidar
        - 3dep (Shallow bathy) https://www.usgs.gov/3d-elevation-program 3D Elevation Program | U.S. Geological Survey
        - BioSCAPE
        - G-liht
        - Airborne Lidar: Zambezi, Louisiana, …
    - Spaceborne:
        - ICESat-2, ICESat/GLAS
        - TanDEM-X, SRTM,
        - Sentinel-1, SDC
        - Planet/skysat, Worldview,
        - SWOT, NISAR, BIOMASS
        - MAXAR bathy (stereophoto)

Database, tools and models (OSSE)

- Develop a prioritized list of targets for airborne campaigns to assess measurement capabilities and performance for determining shallow water bathymetry, wetlands, coastal geomorphology
- Identify existing tools
- Identify and compile database:
  - Airborne
    - Delta-X (Mississippi River Delta): UAVSAR-L, AirSWOT, AVIRISNG, Green bathy Lidar
    - AfriSAR campaign (Gabon): UAVSAR-L, LVIS, DLR's IFSAR X/L/P.
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    - 3dep (Shallow bathy) https://www.usgs.gov/3d-elevation-program 3D Elevation Program | U.S. Geological Survey
    - BioSCAPE
    - G-liht
    - Airborne Lidar: Zambezi, Louisiana, …

  - Spaceborne:
    - ICESat-2, ICESat/GLAS
    - TanDEM-X, SRTM,
    - Sentinel-1, SDC
    - Planet/skysat, Worldview,
    - SWOT, NISAR, BIOMASS
    - MAXAR bathy (stereophoto)

Let’s talk about water.

How will water availability and flow change with climate and increasingly dynamic landscapes?

STV Interdisciplinary Hydrology Discussion seeds

- Interdisciplinary themes and Hydro-goup’s perspective
  - Permafrost with solid Earth
    - HG: water quantities/moisture and flows
  - Wetlands with vegetation
    - HG: impact of vegetation on flows of river/lakes and watersheds.
  - Wetlands with solid Earth
    - HG: impact of elevation and subsidence on vegetation
  - Water surface and flows with solid Earth
    - Erosion and deposition and subsidence
  - Snow depth with cryosphere
    - HG: water impact seasonal snow-mass balance, contribution to stream/river discharge
  - Surface water elevation/bathymetry **baseline** with solid Earth and coastal geomorphology group
    - HG: Water volume capacity, flows within watershed or lakes/rivers
  - Surface water elevation/bathymetry **change** with solid Earth and coastal geomorphology group
    - Erosion and deposition and subsidence
    - HG: impact on flood vulnerability, sediment transport and resuspension
  - Applications….

TABLE 3.2 Science and Applications Priorities for the Decade 2017-2027—The Science and Applications Portion of the Full Science and Applications Traceability Matrix (SATM) in Appendix B

Societal or Science Question/Goal	Earth Science/Applications Objective	Importance
QUESTION H-1. Water Cycle Acceleration. 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-1a.** Develop and evaluate an integrated Earth system analysis with sufficient observational input to accurately quantify the components of the water and energy cycles and their interactions, and to close the water balance from <u>headwater catchments to continental-scale river basins</u>.	Most Important
	H-1b. Quantify <u>rates of precipitation and its phase (rain and snow/ice)</u> worldwide at convective and orographic scales suitable to capture flash floods and beyond.	Most Important
	H-1c. Quantify rates of <u>snow accumulation, snowmelt, ice melt, and sublimation from snow and ice worldwide</u> at scales driven by topographic variability.	Most Important
QUESTION H-2. Impact of Land Use Changes on Water and Energy Cycles. 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.	Very important
	[STV] H-2b. Quantify the magnitude of anthropogenic processes that cause changes in radiative forcing, temperature, snowmelt, and ice melt, as they alter downstream water quantity and quality.	important
	[TO=STV] H-2c. Quantify how <u>changes in land use, land cover</u>, and water use related to agricultural activities, food production, and forest management affect water quality and especially groundwater recharge, <u>threatening sustainability of future water supplies</u>.	Most important
QUESTION H-3. How do changes in the water cycle impact local and regional freshwater availability, alter the biotic life of streams, and affect ecosystems and the services these provide?	**H-3a.** Develop methods and systems for monitoring water quality for human health and ecosystem services.	Important
	H-3b. Monitor and understand the coupled natural and anthropogenic processes that change water quality, <u>fluxes, and storages</u> in and between all reservoirs (atmosphere, rivers, lakes, groundwater, and glaciers) and the response to extreme events.	Important
	[STV] H-3c. Determine structure, productivity, and health of plants to constrain estimates of evapotranspiration.	Important
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.	Very Important
	[STV] 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. (This is a critical socioeconomic priority that depends on success of addressing H-1c and H-4a.)	Important
	H-4c. Improve drought monitoring to forecast short-term impacts more accurately and to assess potential mitigations.	Important
	[STV] 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.)	important

Most Important Objectives

H-1a. Develop and evaluate an integrated Earth system analysis with sufficient observational input to accurately quantify the components of the water and energy cycles and their interactions, and to close the water balance from headwater catchments to continental-scale river basins.

H-1b. Quantify rates of precipitation and its phase (rain and snow/ice) worldwide at convective and orographic scales suitable to capture flash floods and beyond.

H-1c. Quantify rates of snow accumulation, snowmelt, ice melt, and sublimation from snow and ice worldwide at scales driven by topographic variability.

[TO=STV] 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.

TABLE 3.2 Science and Applications Priorities for the Decade 2017-2027—The Science and Applications Portion of the Full Science and Applications Traceability Matrix (SATM) in Appendix B

Societal or Science Question/Goal	Earth Science/Applications Objective	Importance
DS-priority QUESTION S-4. What processes and interactions determine the rates of landscape change?	**S4b.** Quantify weather events, **surface hydrology,** and changes in ice/water content of near-surface materials that produce landscape	Important
QUESTION S-3. How will local sea level change along coastlines around the world in the next decade to century?	**[TO=STV] S-3b.** Determine vertical motion of land along coastlines, at uncertainty <1 mm/yr .	Most important
QUESTION S-6. How much water is traveling deep underground and how does it affect geological processes and water supplies?	**[TO=STV] S-6b.** Measure all significant fluxes in and out of the groundwater system across the recharge area.	Important
	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.	Important
	S-6d. Determine the impact of water-related human activities and natural water flow on earthquakes.	Important

TABLE 3.2 Science and Applications Priorities for the Decade 2017-2027—The Science and Applications Portion of the Full Science and Applications Traceability Matrix (SATM) in Appendix B

Societal or Science Question/Goal	**Earth Science/Applications Objective**	Importance
DS-priority (E-2) What are the fluxes (of carbon, water, nutrients, and energy) *between* ecosystems and the atmosphere, the ocean, and the solid Earth, and how and why are they changing?	**S4b.** Quantify weather events, **surface hydrology,** and changes in ice/water content of near-surface materials that produce landscape	Important
DS-priority (E-3) What are the fluxes (of carbon, water, nutrients, and energy) *within* ecosystems, and how and why are they changing?	**[TO=STV] S-3b.** Determine vertical motion of land along coastlines, at uncertainty <1 mm/yr .	Most important
	[TO=STV] S-6b. Measure all significant fluxes in and out of the groundwater system across the recharge area.	Important
	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.	Important

Conclusion and observation from Global Hydrological Cycles and Water Resource Panel

- Although mentioned, the Decadal Survey does not provide requirements for topography.
- Water-related variables to address the most important hydrological science challenges and to water resource applications include: **soil moisture**, **stream flow**, **lake and reservoir levels**, **snow cover**, **glaciers and ice mas**s, **evaporation and transpiration**, **groundwater**, **water quality**, and **water use**.
  - However, high-resolution precipitation measurements emerged as a high priority with the Decadal Survey's Hydrology panel.
- While some objectives were not associated with STV, its potential ability to provide measurements of snow depth and topography could directly contribute, for example, to these objectives:
  - **H-1a.** Develop and evaluate an integrated Earth system analysis with sufficient observational input to accurately quantify the components of the water and energy cycles and their interactions, and to close the water balance from headwater catchments to continental-scale river basins.
  - **H-1c.** Quantify rates of snow accumulation, snowmelt, ice melt, and sublimation from snow and ice worldwide at scales driven by topographic variability.

STV meeting prep

- Develop Next decadal survey's hydrology discussion
  - Knowledge/Science gaps and questions
- Develop science reqs
  - Revisit white paper
- Develop measurement reqs
  - Revisit white paper
- Interdisciplinary themes and Hydro-goup's perspective
  - Permafrost with solid Earth
    - HG: water quantities/moisture and flows
  - Wetlands with vegetation
    - HG: impact of vegetation on flows of river/lakes and watersheds.
  - Wetlands with solid Earth
    - HG: impact of elevation and subsidence on vegetation
  - Water surface and flows with solid Earth
    - Erosion and deposition and subsidence
  - Snow depth with cryosphere
    - HG: water impact seasonal snow-mass balance, contribution to stream/river discharge
  - Surface water elevation/bathymetry **baseline** with solid Earth and coastal geomorphology group
    - HG: Water volume capacity, flows within watershed or lakes/rivers
  - Surface water elevation/bathymetry **change** with solid Earth and coastal geomorphology group
    - Erosion and deposition and subsidence
    - HG: impact on flood vulnerability, sediment transport and resuspension
  - Applications….