



Advancing Global Snow Observations: An approach for research to operations

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The Importance of Snow



Seasonal snow is uniquely important to the Earth's System

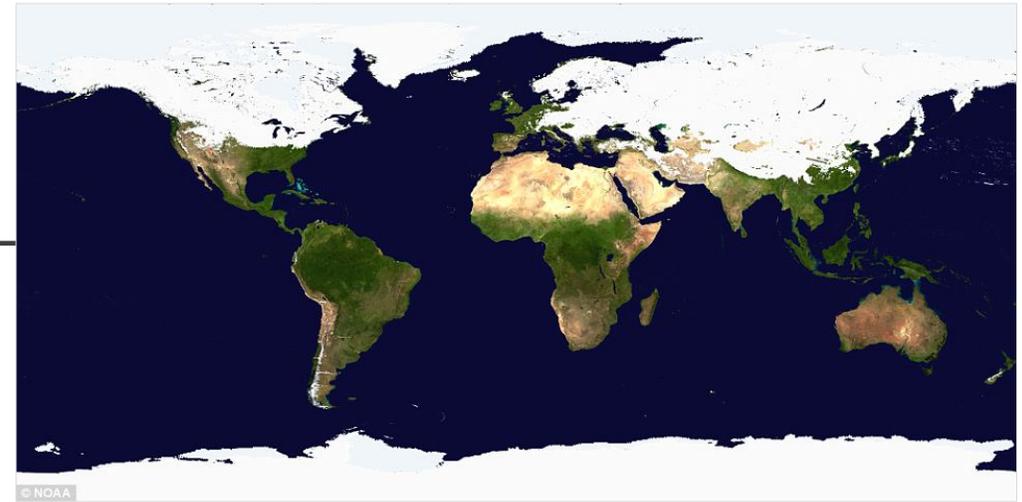
- Significant component of the global energy balance, covering 31% of the land surface
- More than one-sixth of the world's population (1.2 billion people) relies on seasonal snowpack and glaciers for,
 - Water Supply
 - Agriculture
 - Hydropower
 - Recreation
- Critical to wildlife and vegetation ecosystems
- Snow melt can contribute to widespread and damaging floods.

Satellite Observations

Remote sensing is well-suited to provide spatially distributed, near real-time observations of global snow

Critical Snow Observations:

- Albedo
 - Snow Covered Area
 - SWE/Snow Depth
- Progress made in recent decades.
 - Mature algorithms and satellite observations available
- ← Biggest gap in snow remote sensing: Need combined, multi-observational, modeling approach to develop global estimates



© NOAA
Composite image of northern hemisphere snow covered area in February 2011, produced by NOAA with MODIS Terra imagery.

No satellite sensor has demonstrated ability to accurately measure global SWE

- Forests (half the snow-covered world)
- Snow characteristics: wet snow, deep snow, shallow snow, metamorphism
- Complex terrain
- Clouds, atmospheric propagation

THP Snow Program

The NASA Terrestrial Hydrology Program (THP) aims to advance global snow remote sensing to address these Science and Application goals:

Science Goal: To understand the time and space variation in the snow's energy and mass balances and complex feedbacks with the Earth's climate, water cycle, and carbon cycle.

Application Goal: Improve fresh-water resources information for: Drinking Water, Food Production, Energy Production, Transportation, Industry and Manufacturing, Recreation. Improve flood, drought, avalanche, and debris-flow hazard forecasts and decision-support. Improve local-to-global weather prediction.



Satellite Observations:

Upcoming opportunities and new developments

In this decade several potential opportunities for spaceborne snow observations are possible:

- Earth Venture Mission
- Earth System Explorer (ESE)
 - Identify possible satellite technologies that meet criteria of mission
 - Define activities required to evaluate potential concepts
- NISAR – L-band InSAR
- Terrestrial Snow Mass Mission (TSMM) – Canadian mission, Dual Ku-band SAR
- SBG – Hyperspectral designated observable

In addition, new techniques and advances are being demonstrated with existing satellites:

- C-band SAR - Sentinel-1
- Stereo-photogrammetry – Worldview, Planet, Pleiades
- Spaceborne lidar – ICESat-2, GEDI



Global Snow System

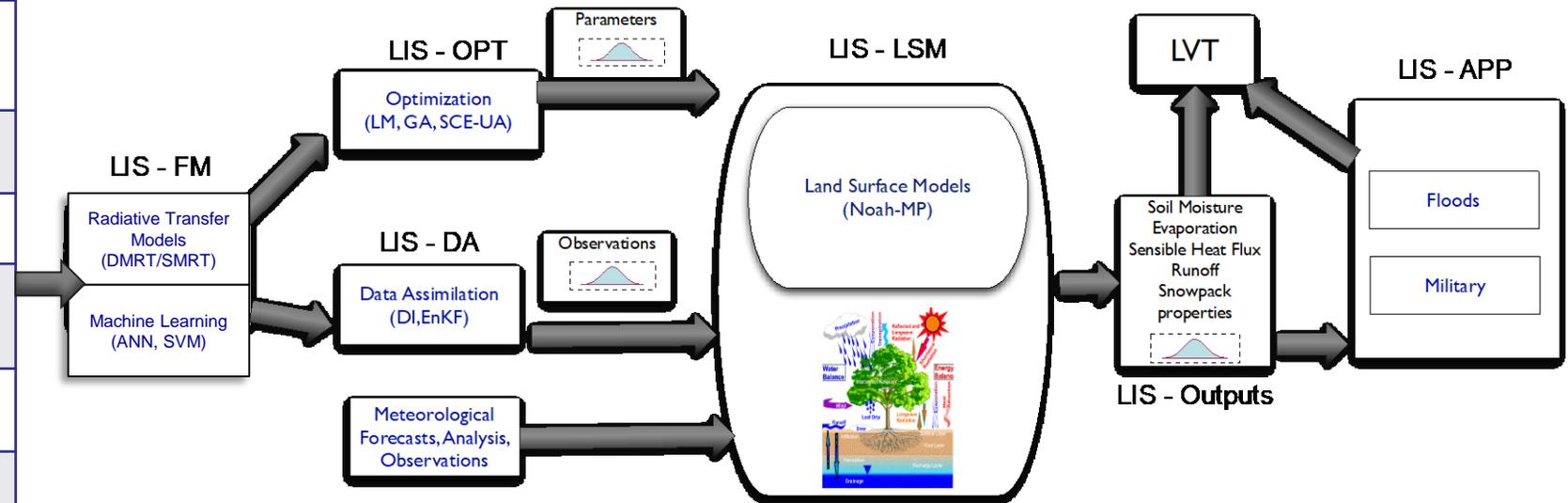
Computational framework that ingests multi-scale in-situ and remotely sensed observations into a physically-based modeling system.

Existing or potential satellite that could be leveraged to develop global snow estimates

Currently Available		Proposed or Expected	
Sensor	Data	Sensor	Data
Sentinel-1 (C-band SAR)	SWE	TSM11 (Ku SAR)	SWE, dB
AMSR2/SSMIS (Passive mw)	SWE, Tb	CIMR (Passive mw)	SWE, Tb
VIIRS, MODIS (VIS/IR)	SCA, Albedo	SWOT (Ka InSAR)	Height
Hi-res stereo optical	Depth, SCA, albedo	NISAR (L+S band SAR)	SWE
IceSat2, GEDI (lidar)	Height	SBG (hyperspectral)	Albedo
GRACE-FO	TWS	MWI (Passive mw)	SWE, Tb

NASA Land Information System (LIS)

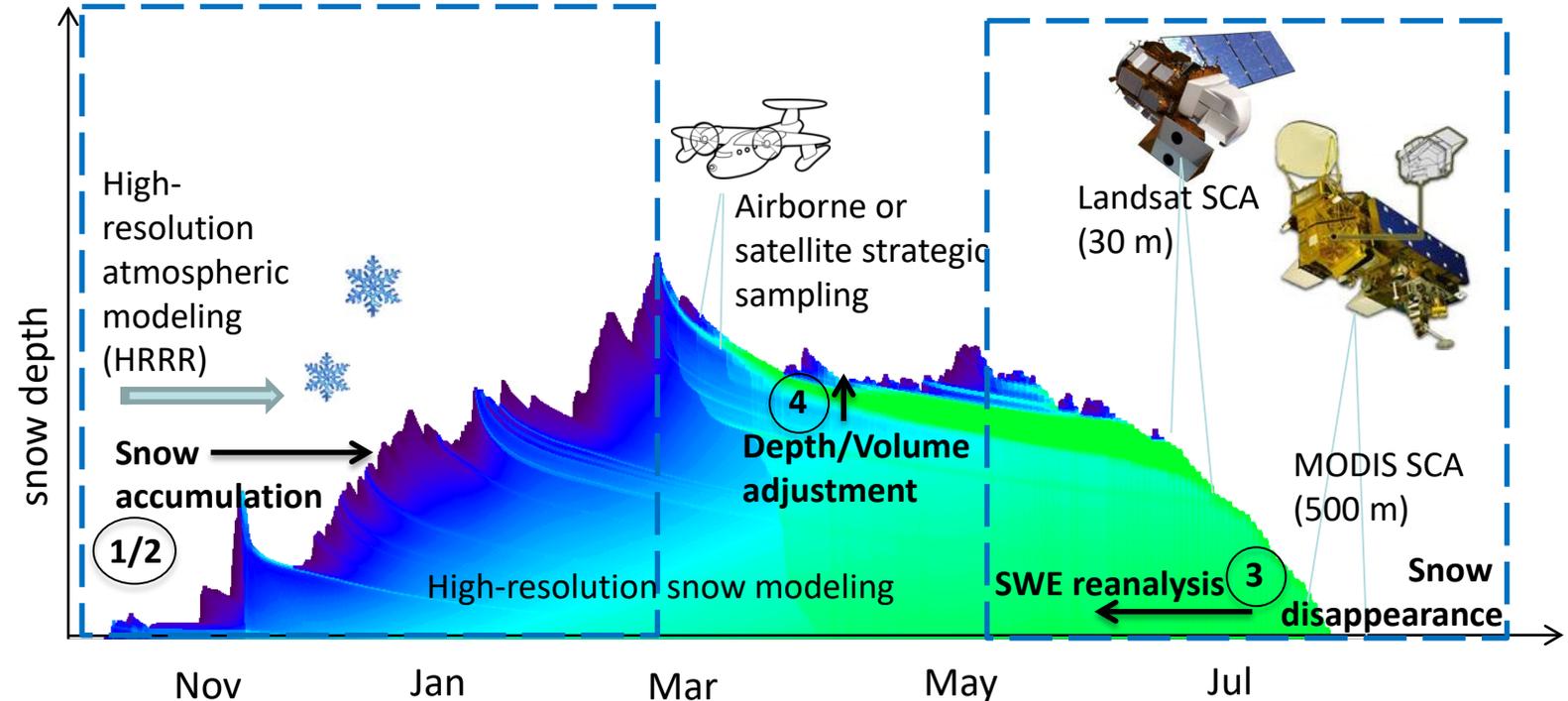
- LIS is a software framework to study land surface processes and land-atmosphere interactions
- Includes a broad set of computational subsystems for realizing the information content of observational data.



Optimize the system

Key points: published findings

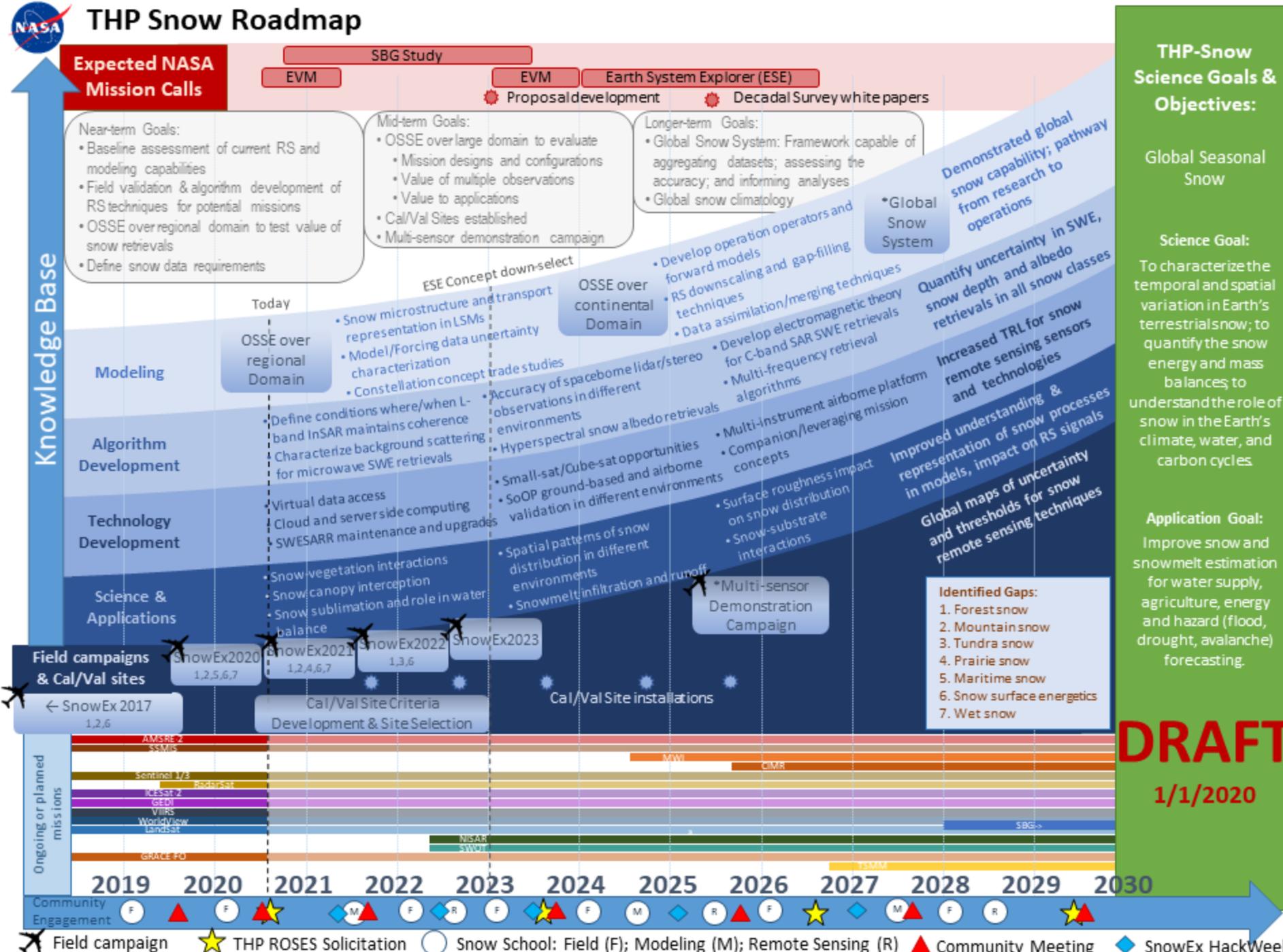
- 1) Getting precipitation (snowfall) right is the most important step to accurately modeling snow water equivalent (Raleigh et al. 2016)
- 2) In the western U.S. mountains, well-configured, high-resolution atmospheric models are currently better estimates of annual precipitation than gridded observations (Lundquist et al. 2019)
- 3) Snow patterns on the ground are repeatable across years (Sturm and Wagner 2010; Vogeli et al. 2016; Pflug and Lundquist 2020)
- 4) Sampling snow depth and variability once near peak SWE is enough to correct the majority of snow model errors for the remainder of the season. (Hedrick et al. 2018; Vogeli et al. 2016)



- We have many pieces already.
- Check for exceptions to the rule: Are these findings applicable globally?
- We need a dedicated investment to put them together and to vet and optimize the system.
- Multiple new satellite options could fit in this paradigm.

THP Snow Roadmap

The THP Snow Community has developed a near- to medium-term plan for future activities designed to prepare the snow community to be ready for upcoming opportunities, improve global snow characterization capabilities and meet identified snow data needs.



THP-Snow Science Goals & Objectives:

Global Seasonal Snow

Science Goal: To characterize the temporal and spatial variation in Earth's terrestrial snow; to quantify the snow energy and mass balances to understand the role of snow in the Earth's climate, water, and carbon cycles

Application Goal: Improve snow and snowmelt estimation for water supply, agriculture, energy and hazard (flood, drought, avalanche) forecasting.

DRAFT
1/1/2020



THP Snow Roadmap





NASA SnowEx

Multi-year field experiment, designed to prepare for snow satellite missions to observe global snow water equivalent and albedo.

- Includes extensive airborne and surface-based observations to evaluate different snow remote sensing technologies throughout the season in various landscapes.
- Help address key issues impacting snow remote sensing and algorithm development.

SnowEx 2017 – Colorado, focused on multiple instruments in forest gradient

SnowEx 2020 – Western US, focused on Time Series of L-band InSAR, Active/passive microwave for SWE and Thermal IR for snow surface temp

SnowEx 2021 – Western US, Continue Time Series, L-band InSAR, also address Prairie & Albedo questions

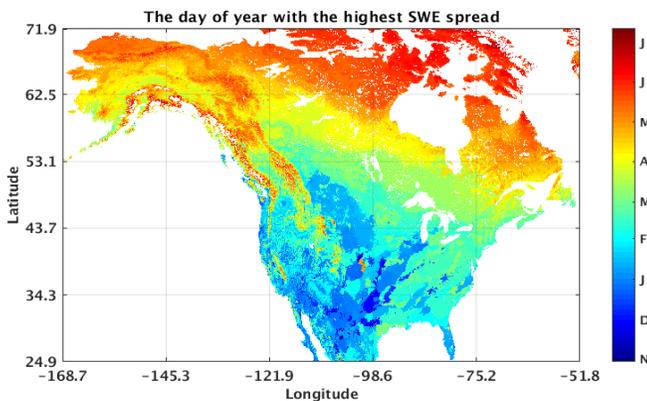
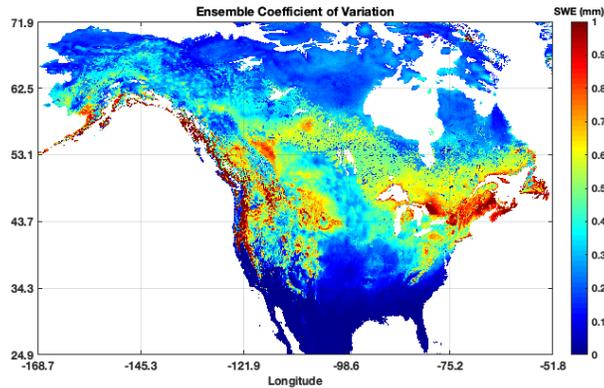
SnowEx 2022 – Tundra/Taiga focus; plans developed to address SWE/snow depth and albedo objectives; Currently evaluating & prioritizing needs

SnowEx 2023 – TBD; Small scale, Need input on remaining needs



Images: Instrumented aircraft flying towards Grand Mesa study site in 2017 (top left); Snow surface albedo measurements (top right); Snow pit at Senator Beck Basin study site showing dust layers and snow density profile (<http://communitysnowobs.org/dust-snow-mckenzie-skiles/>), bottom left); ground-based radiometer observations collected through the season (bottom right).

Modeling/OSSE

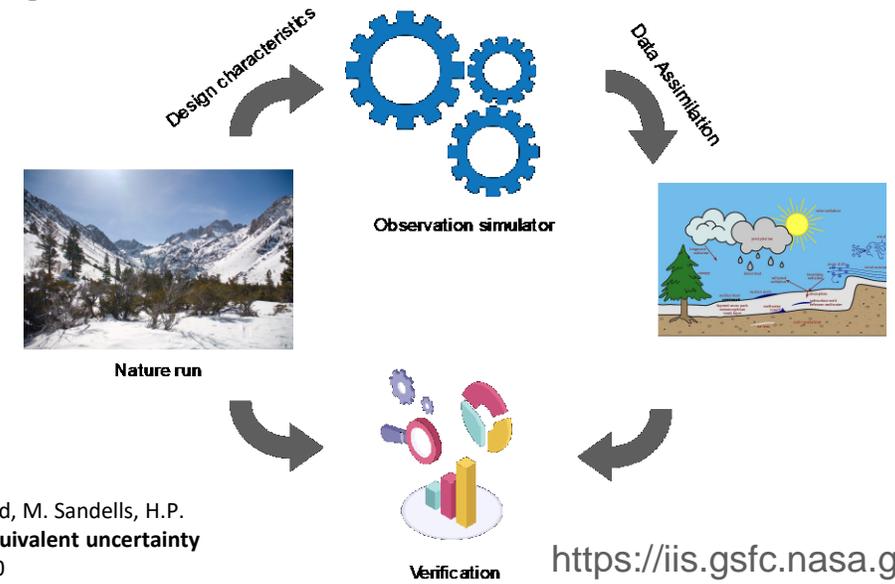


1. Uncertainty in continental scale snow estimation

- Quantified with an ensemble of land surface models (JULES, Noah, NoahMP, Catchment) and forcing datasets (MERRA2, GDAS, ECMWF)
- Largest variability/uncertainty in SWE is found in regions with the deepest snow, areas with complex topography, and dense vegetation.
- Largest spread in SWE is found near the peak or melt season, not in the accumulation period; Times of SWE variability move from south to north during the melt season

2. NASA Land Information System (LIS) as a hydrology OSSE tool

- Several technical, computational, and scientific challenges for the successful use of OSSEs.
- NASA LIS includes the functional support for end-to-end hydrology OSSEs



Kim, R.S., S. Kumar, C. Vuyovich, P. Houser, J. Lundquist, L. Mudryk, M. Durand, A. Barros, E. J. Kim, B. A. Forman, E. D. Gutmann, M. L. Wrzesien, C. Garnaud, M. Sandells, H.P. Marshall, N. Cristea, J. M. Pflug, J. Johnston, Y. Cao, D. Mocko, and S. Wang, **Snow Ensemble Uncertainty Project (SEUP): Quantification of snow water equivalent uncertainty across North America via ensemble land surface modeling**, Preprint under review for The Cryosphere Discuss., <https://doi.org/10.5194/tc-2020-248>, 2020



Research to Operations

- Operational airborne systems have greatly enhanced the SnowEx campaigns. These campaigns could also help validate and advance operational systems for improved future capability.
- Findings from these research efforts can be transferred to operational modeling systems; directly, in the case of the USAF, who has adopted the LIS system for global weather prediction. Research findings regarding model physics and scaling should be transferrable to other systems as well.
- Significant effort is needed in developing and analyzing techniques for merging these data, i.e. data assimilation, machine learning. The data storage and computational demands will not be insignificant. Need to think about future needs now.
- For greatest benefit, we need early communication between research efforts and operational needs.



For more information about the THP Snow Program

Visit: snow.nasa.gov

Or contact: carrie.m.vuyovich@nasa.gov



Photo credit: J. Lund



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