Building a Snow Model Capable of High Spatial Resolution Simulations into the Land Information System (LIS)

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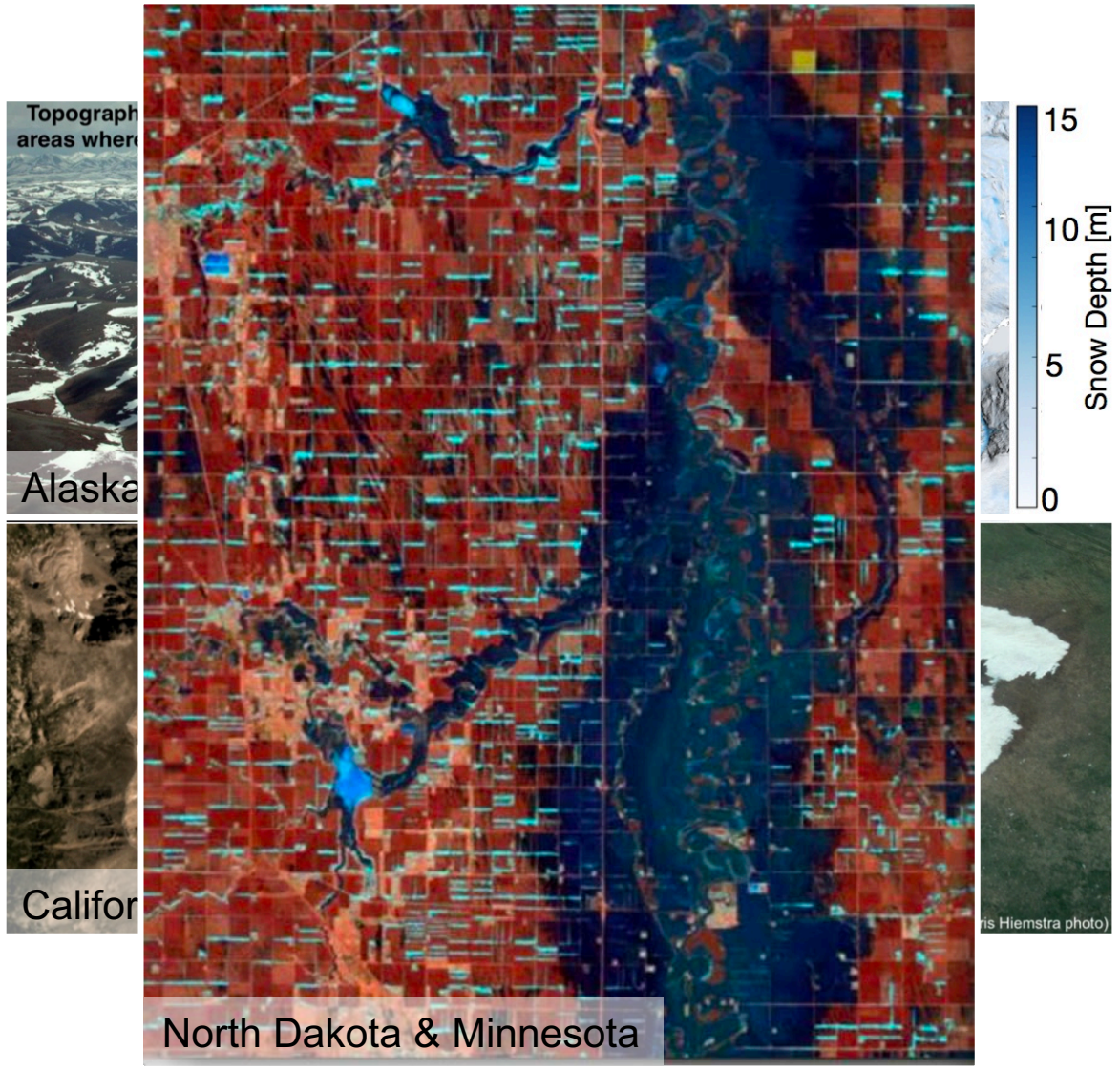
Program: AIST-18

The need for high-resolution snow in LIS

The Earth System and Society:

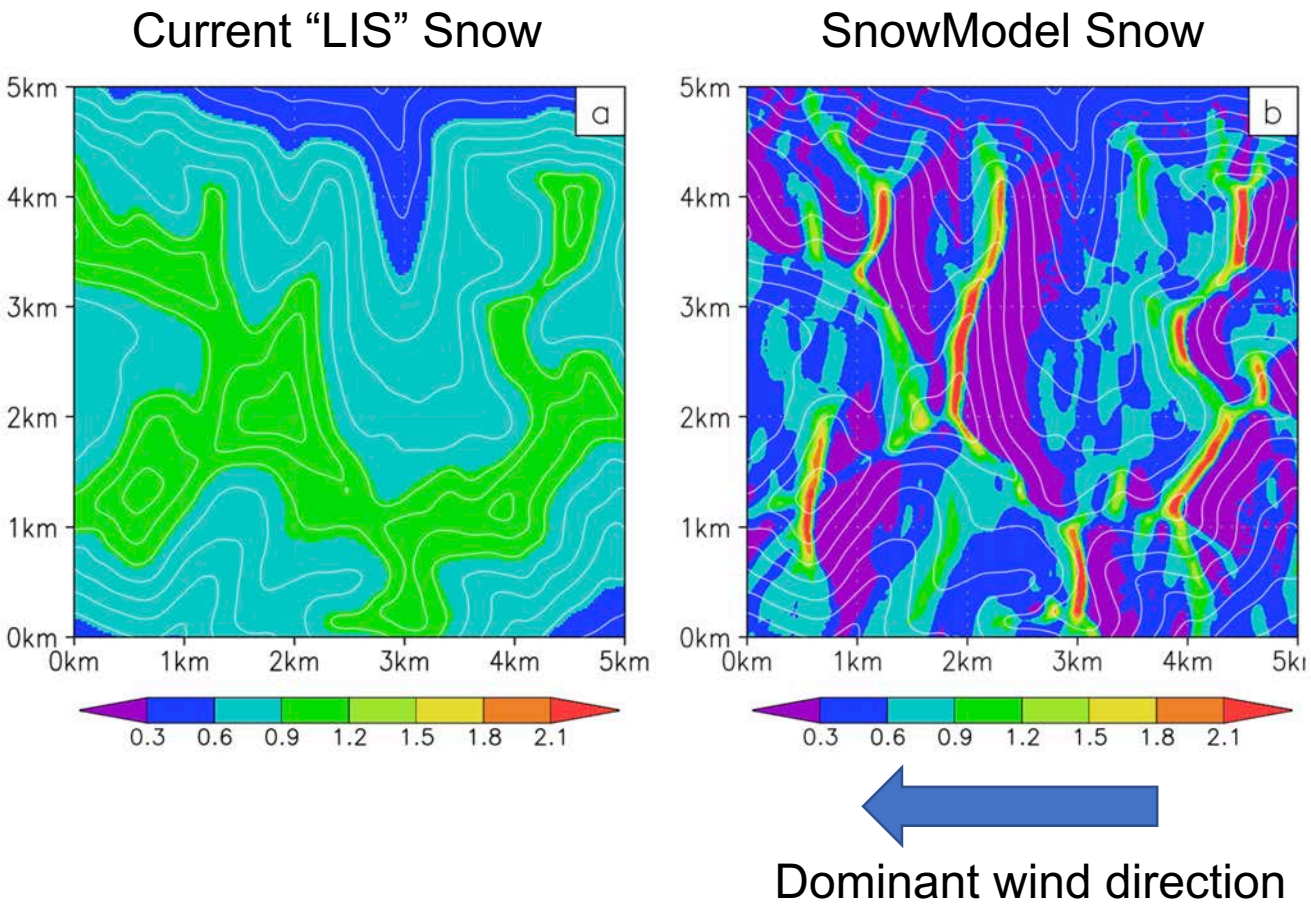
- Snow is a critical water resource; it is susceptible to climate change, and the albedo feedback will change climate and weather.
- LIS snow is used for mission planning and data assimilation.
- The representation of snow in LIS now is one dimensional
- Real snow is extremely heterogenous
- Variability comes from processes not represented in LIS



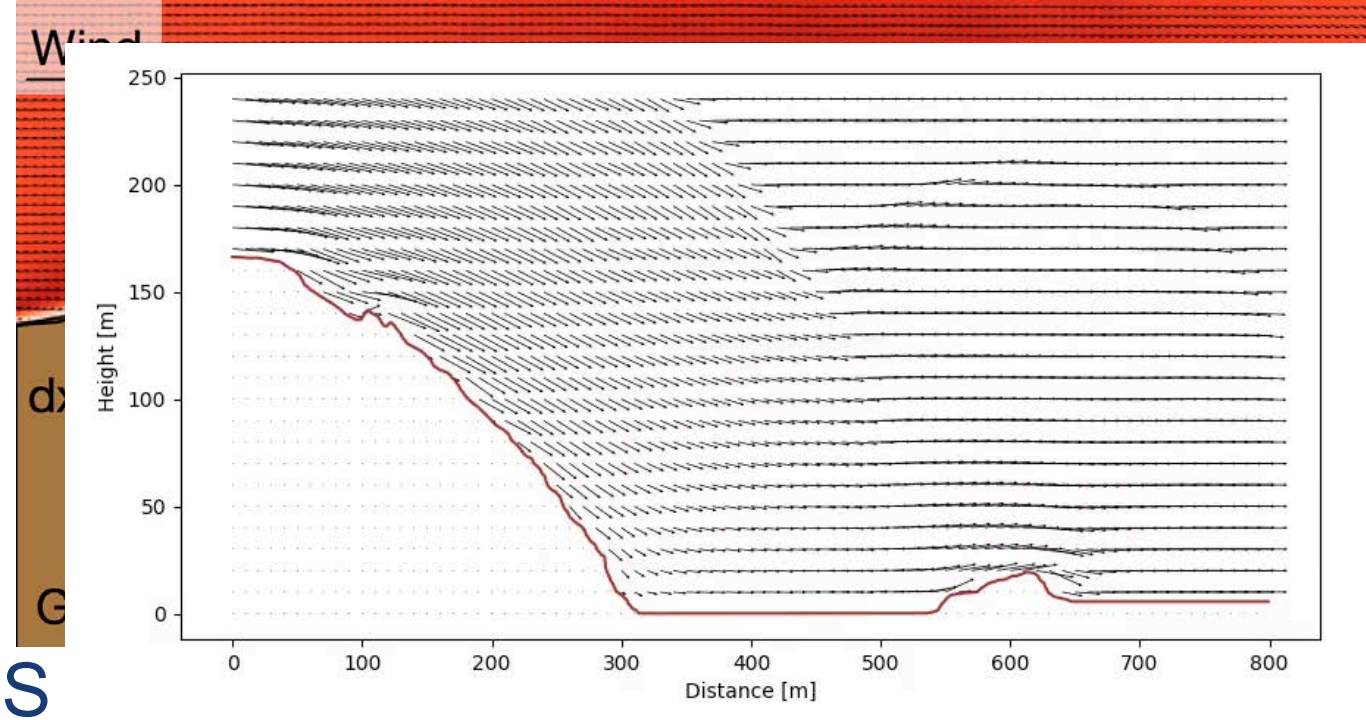
Adding SnowModel to LIS provides key processes

Adding Processes

- High-resolution wind field over terrain
- Adjustments to solar radiation, temperature, and precipitation
- Snow transport and deposition
- Snow surface cohesion



Technical Details



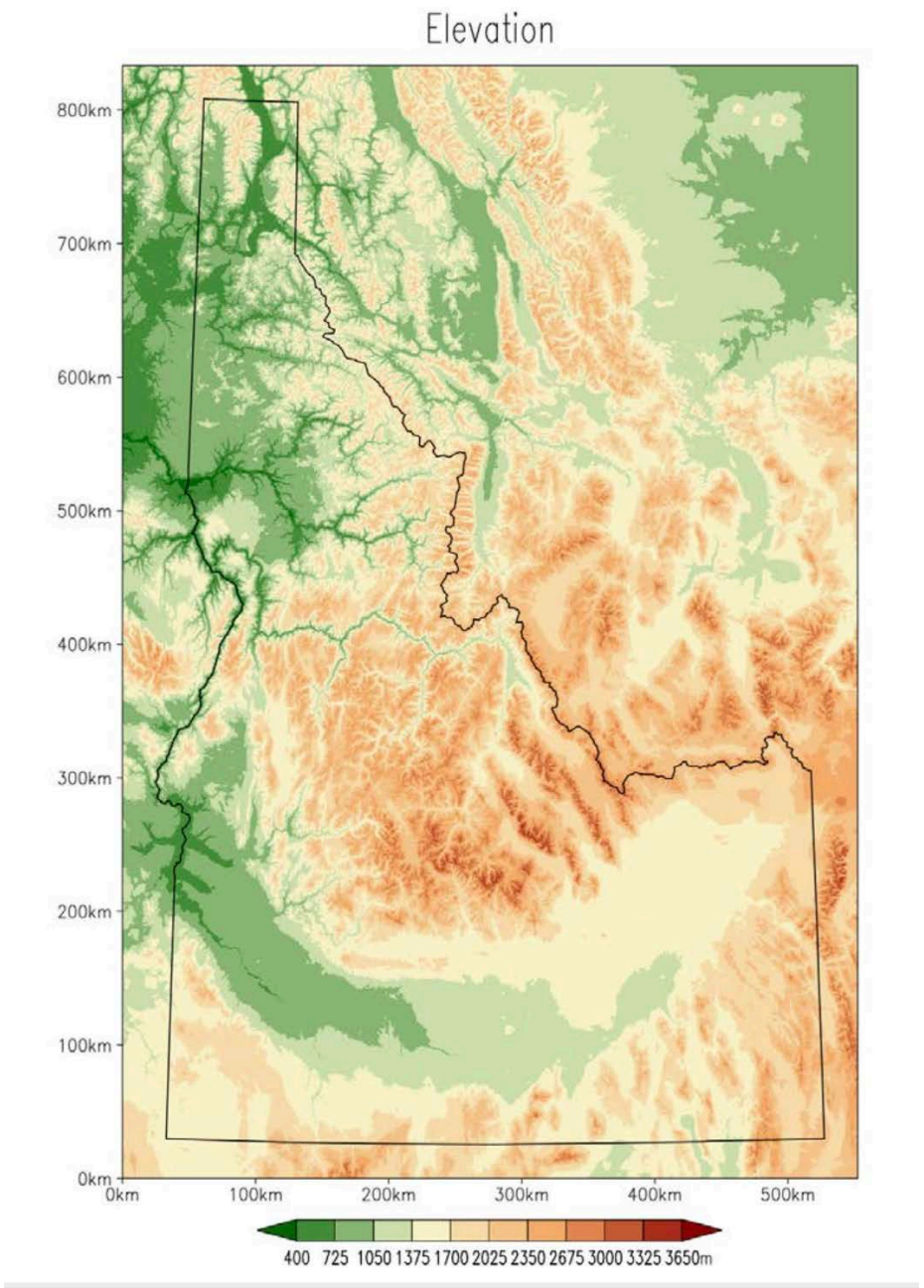
- Addition of MicroMet winds
- Coupling of SnowModel in LIS
  - Parallelization of SnowModel is non-trivial
  - Adding ability to communicate across processes in a LIS model
  - Connection between SnowModel and Noah-MP land model
  - Ability to use distributed memory to permit CONUS scale O(100m) grid simulations.
- Optimization and tuning, possibly parallel file IO in LIS
- Testing in continental domain OSSE to show impacts

Computational Scaling

- SnowModel simulations are serial
- Current large domain:
  - 6,140 x 9,258 grid cells
  - 24yr simulation
  - CPU: 269 days + 8:39:42

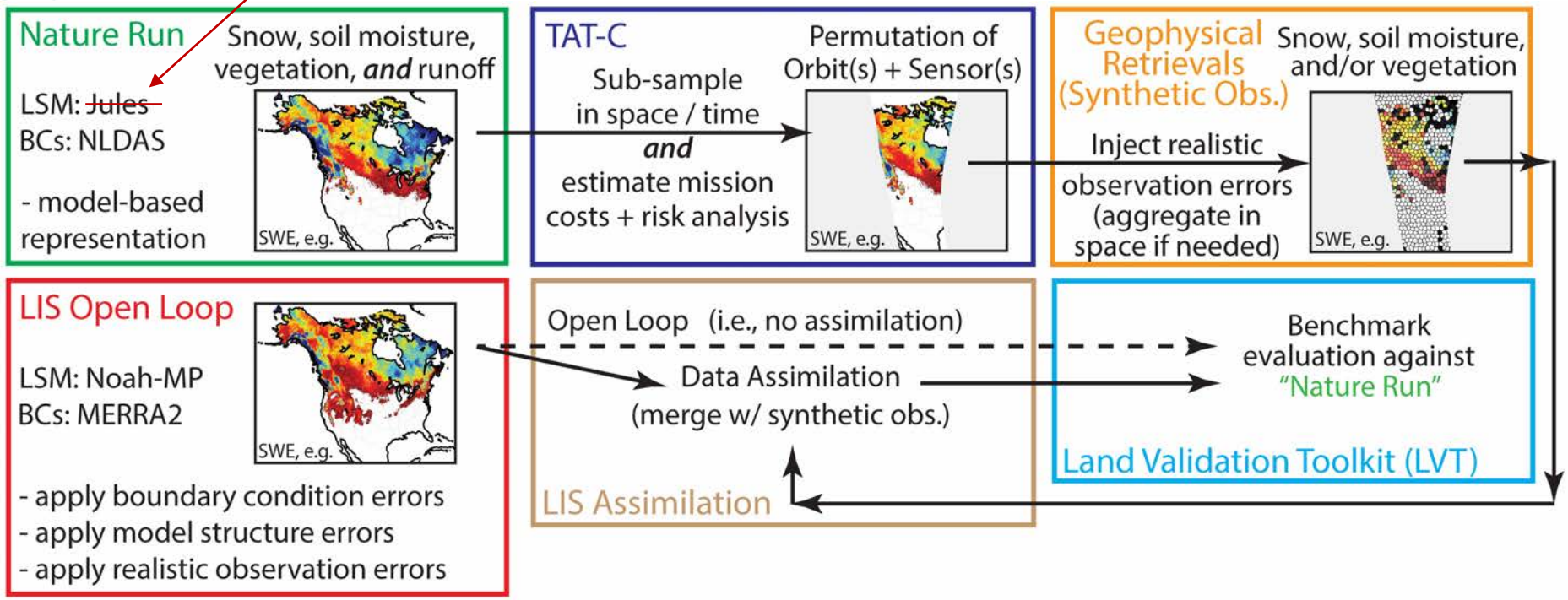
- CONUS domain will be ~50x larger

Goal: parallelize ~100-1000x efficiently



Technical Details

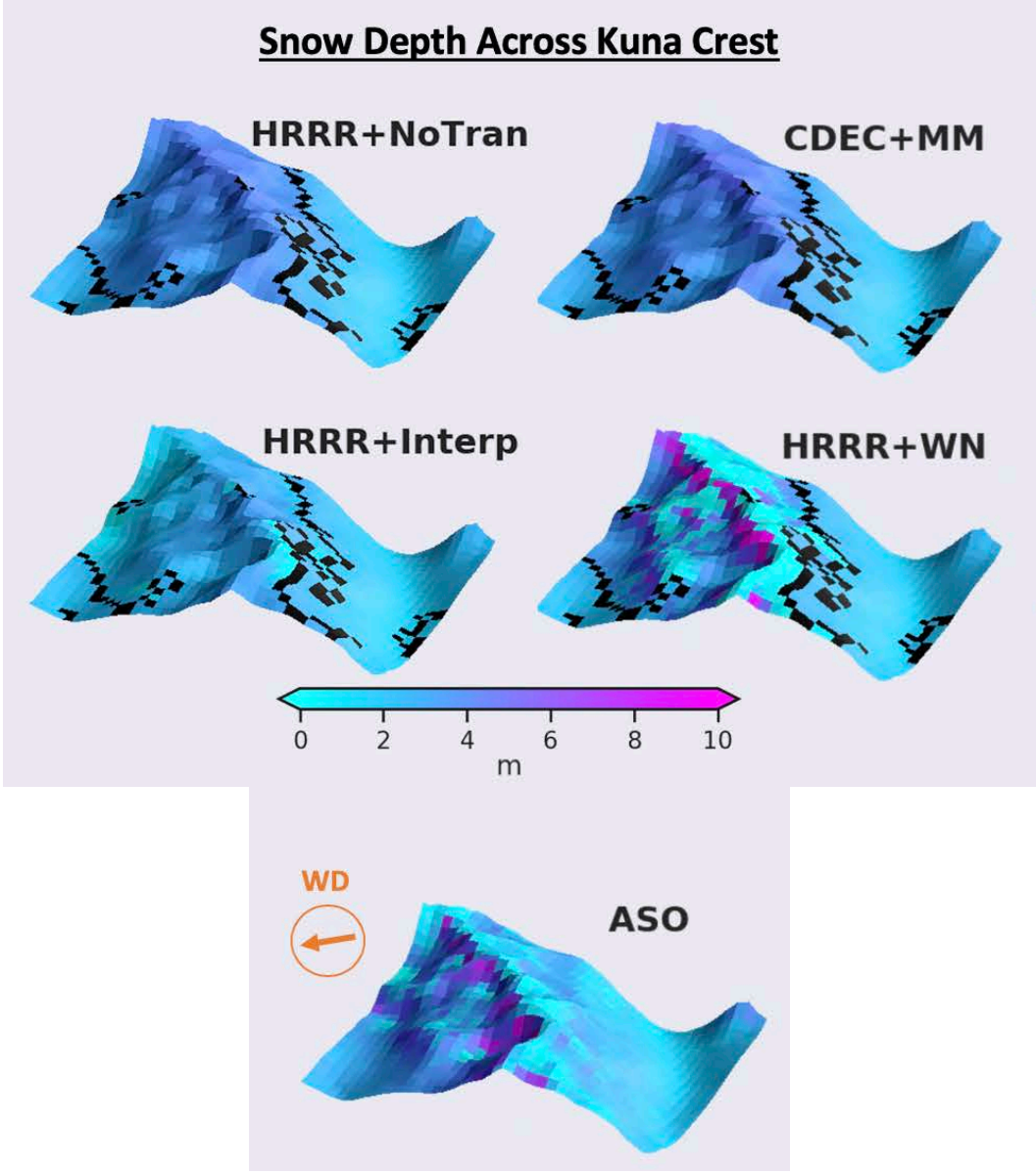
Bringing SnowModel into a continental scale OSSE



Innovation: ``**fraternal twin" experiment rather than "identical twin"** (AIST-16-0024)
Building on OSSE development with AIST-18-0041

Initial Progress

- Importance of the input windfield
- Many existing tools need to be reworked to operate at necessary scales (e.g. input file scripts)
- Existing snow transport algorithm in SnowModel not optimal for parallelization
- (most) serial code implemented in LIS
- Modernization of SnowModel code (F95+) has resulted in >2x speedup of serial code in some cases.



Reynolds et al 2020

Next Steps / Contributions

- Representing snow spatial variability is important for mission planning
- LIS currently lacks snow redistribution
- SnowModel represents redistribution, lacks parallel scaling and LIS-DA-OSSE
- Appropriate wind fields are crucial for modeling snow variability
- Integrating SnowModel in LIS will provide improved snow mission planning and operating capabilities
- SnowModel provides many new science capabilities for LIS

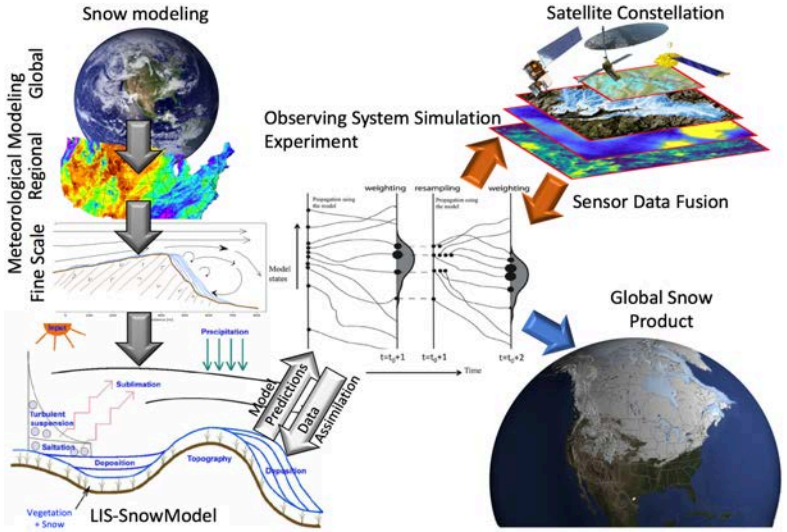
Back Up Slides

Preparing NASA for Future Snow Missions: Incorporation of the Spatially Explicit SnowModel in LIS

PI: Ethan Gutmann, National Center for Atmospheric Research

Objective

- Improve analysis of snow mission design cost-benefit tradeoffs
- Extend the NASA Land Information System Framework (LISF) to simulate critical sub-km scale snow variations.
- Enhance LIS-SnowModel system to be capable of continental scale sub-km grid simulations
- Improvement of local meteorology forcing data for LISF in complex terrain



Snow Modeling OSSE and Data-Fusion Framework

Approach

Extend the NASA Land Information System Framework (LISF) to simulate critical snow processes:

1. Incorporate SnowModel's MicroMet in LISF to enhance the surface meteorological fields produced by LISF
2. Add SnowModel's SnowPack and snow redistribution capabilities to extend the snow modeling capabilities in LISF.
3. Implement and optimize multi-node parallel computing capability into LISF-SnowModel to permit large, high-resolution simulations.
4. Utilize the new LISF-SnowModel capabilities for the NASA-SnowEx Snow Ensemble Uncertainty Project (SEUP) and a dedicated Observing System Simulation Experiment (OSSE).

Co-Is/Partners: Barton Forman (UMD), Glen Liston (CSU), Jessica Lundquist (UW), Carrie Vuyovich (GSFC), Kristi Arsenault (GSFC), Shugong Wang (GSFC), Adele Reinking (CSU), Andrew Newman (NCAR), Sujay Kumar (GSFC)

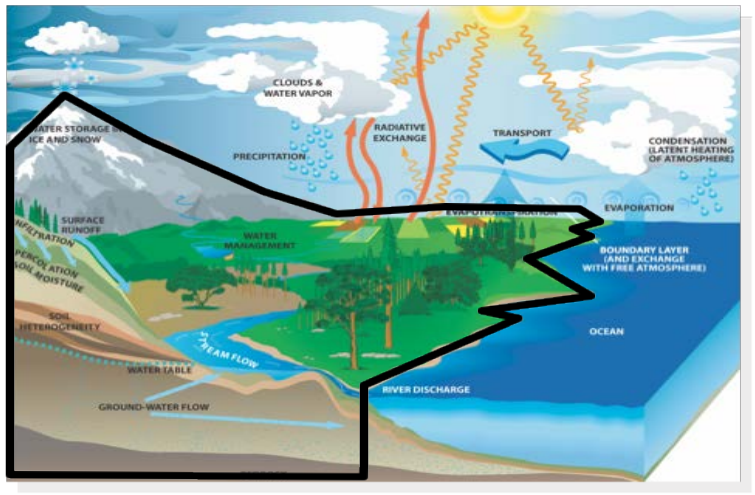
Key Milestones

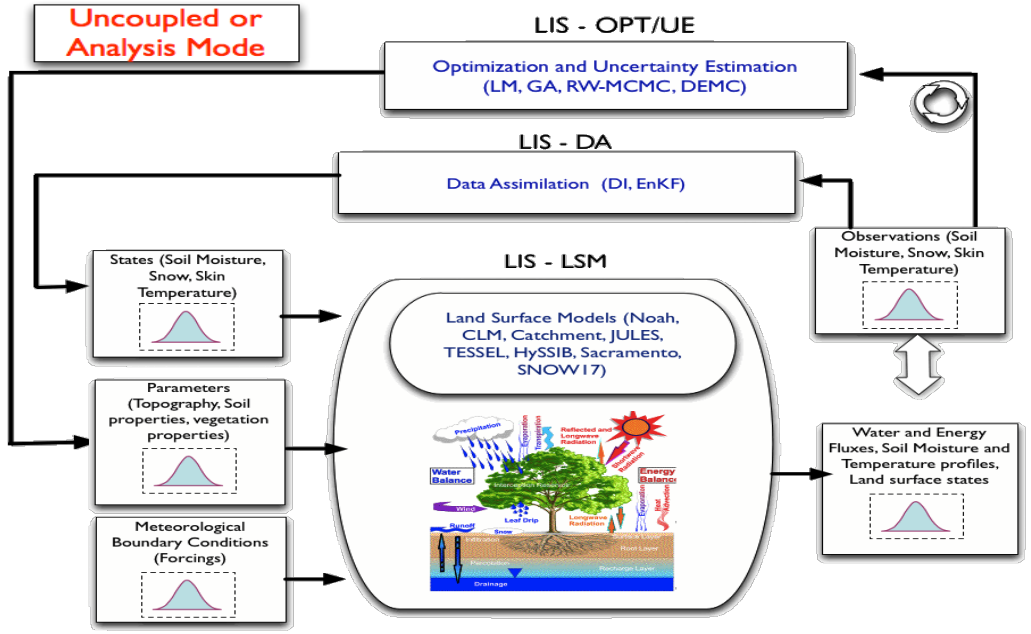
- MicroMet routines used in LISF for existing LSM in regional simulations over the SnowEx test domains. 12/20
- SnowModel is used in LIS to complete a multi-year regional simulation over the SnowEx test domains. 03/21
- SnowModel is used in LIS to complete a 30-year continental domain simulation. 09/21
- Continental domain LIS-SnowModel simulations are used with the synthetic observation operator as the Nature run for NASA-SEUP snow OSSE. 03/22

$TRL_{in} = 2$ **$TRL_{current} = 2$**

Land Information System (LIS)

- Study **land surface processes** and land-atmosphere interactions
- Integrates satellite- and ground-based **observational data** products with land surface **modeling techniques**



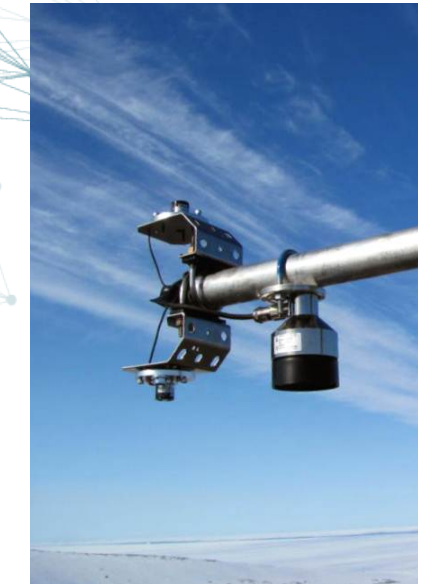


Kumar et al. (2006), Land Information System: An interoperable framework for high resolution land surface modeling, Environmental Modeling and Software

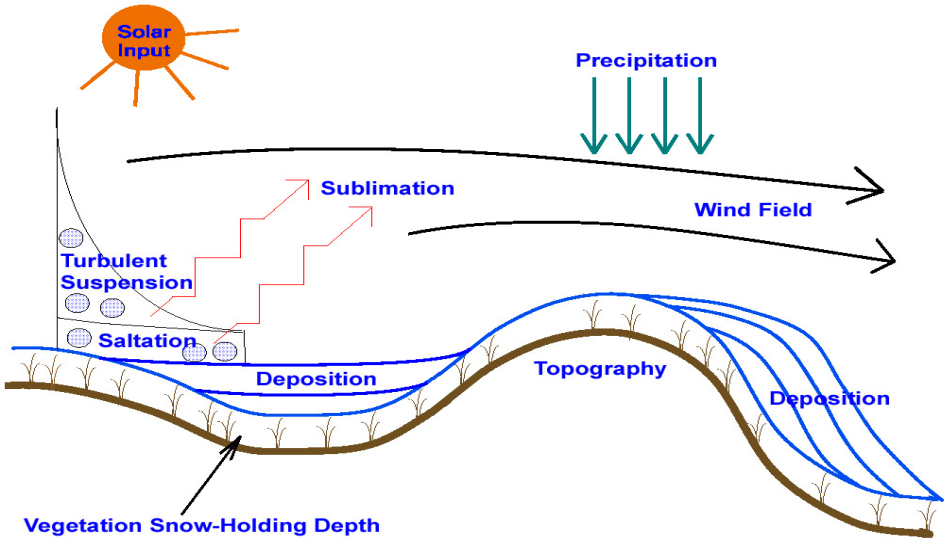
SnowModel: A Spatially Distributed Snow-Evolution Modeling System

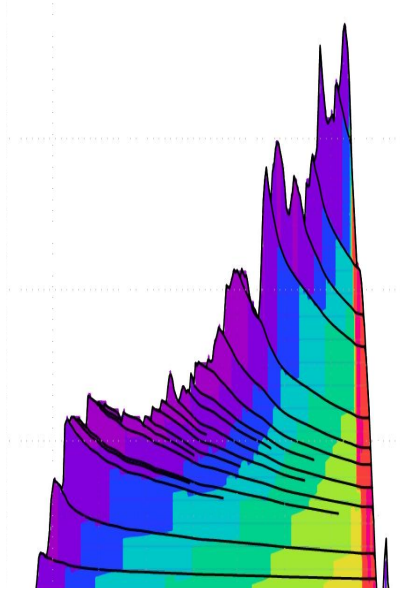
(Liston and Elder 2006b)

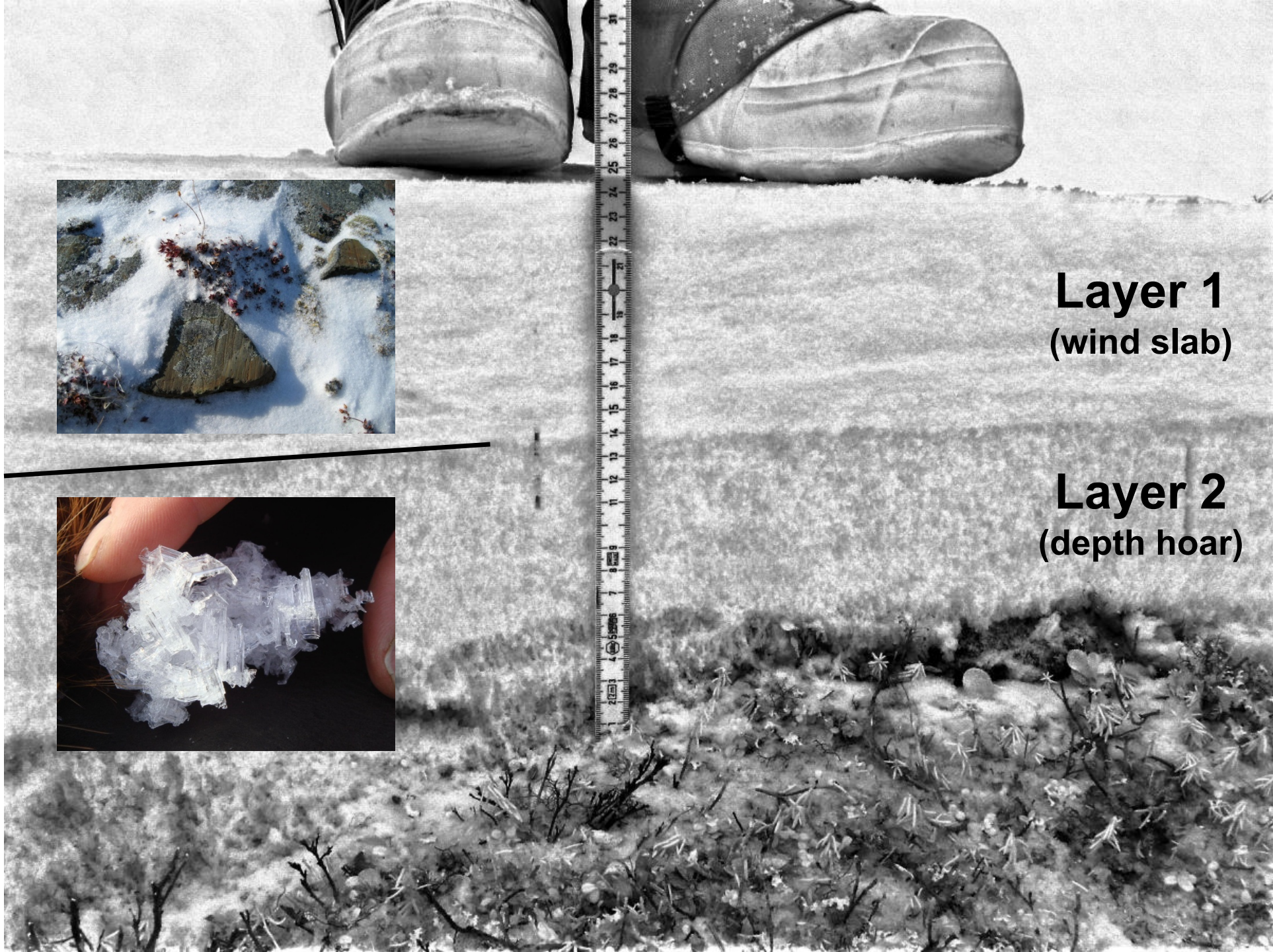
MicroMet – Micro-Meteorological Distribution Model (Liston and Elder 2006a)
EnBal – Surface Energy Balance/Melt Model (Liston et al. 1999)
SnowPack –Multi-Layer Snowpack Model (Liston and Mernild 2012)
SnowTran-3D – Blowing and Drifting Snow Model (Liston and Sturm 1998; Liston et al. 2007)
SnowAssim – Snow Data Assimilation Model (Liston and Hiemstra 2008)



SnowTran-3D; Liston and Sturm (1998)






Layer 1
(wind slab)
Layer 2
(depth hoar)

Snow Drifts

(Potential Polar Bear Denning Sites)