Modeling Snow: For Observation or From Observation?

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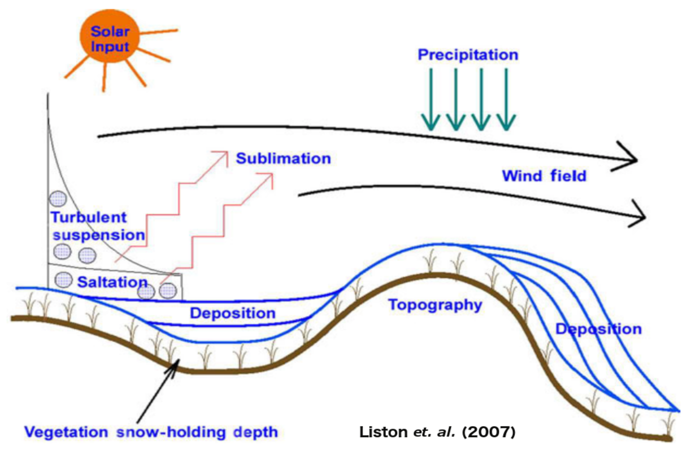
Introduction

- Our focus: Snowfall ⇒ Snow distribution on surface ⇒ Melt
- Energy for melt is limited per unit area
- Inaccurate snow distribution will give incorrect melt and runoff and inaccurate timing and magnitude of discharge in hydrographs
- Scarcity of data in remote locations (for ex, Arctic Tundra) is a major problem
- High Resolution Distributed Computational Models are required
  - ⋆ **How much dependence ???**
- High Resolution: ∼ 10 - 1 meter

Key Player

- Challenges of snow distribution are different in different topography
- Main Role: **Wind**
  - ⋆ Wind driven preferential deposition of snowfall
  - ⋆ Wind driven rearrangement
  - ⋆ Wind+Topography+Vegetation interacted snow distribution



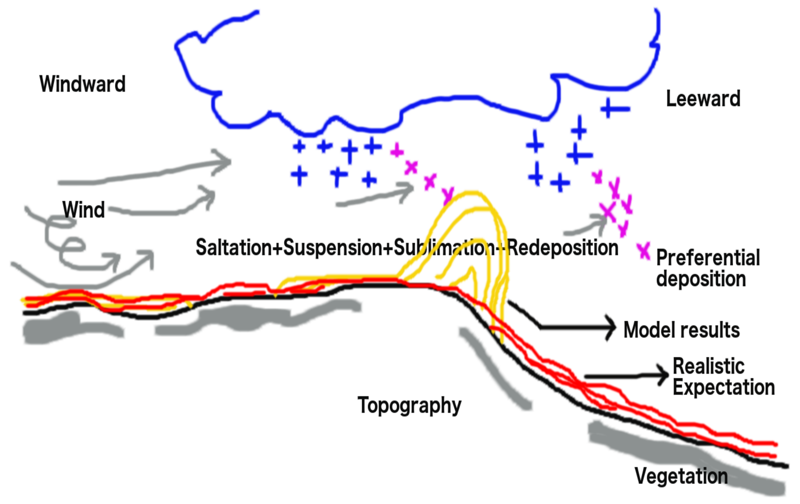
Goals in modeling snow

- Understand Snow-Wind interaction through **physical processes**
- What are they?
  - ⋆ Precipitation distribution over varying elevation and vegetation
  - ⋆ Saltation, Suspension & Sublimation
  - ⋆ Blowing snow distribution
- Expectations from models
  - ⋆ Accurate distribution along drifts
  - ⋆ Accurate depth and SWE over time
  - ⋆ **Model - LiDAR Observation ⟹ 0**

Problems & Challenges in Modeling

Arctic Tundra

Wind driven



Snow tower formation

Alpine Mountain

Wind+Gravitation driven

Complexities of Snow-Wind Coupled Distribution Models

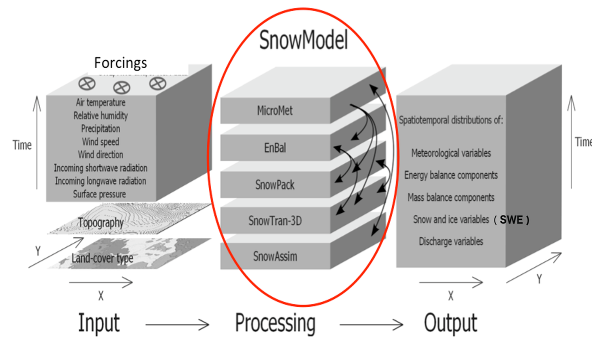
- Existing physics motivated approaches
  - ⋆ Solve linearized momentum equations using Fourier transforms of topography specified by a Digital Elevation Model (DEM)
  - ⋆ Topographic modification of wind speeds and distribution by an empirical weighting factor
  - ⋆ Two layer frictional velocity approach for transport
  - ⋆ Generate wind fields from mesoscale atmospheric models which solve simplified forms of Navier-Stokes equations with Large Eddy Simulations (LES)
  - ⋆ Transport by solving diffusion equation with finite element method
- Ideal approach
  - ⋆ Numerically solve FULL Navier-Stokes equations (NOT by LES) for the wind fields
  - ⋆ Use Lagrange Particle Tracking method to track snow particle trajectories over wind fields
  - ⋆ For preferential deposition & blowing snow events

Do we need to go that far ???

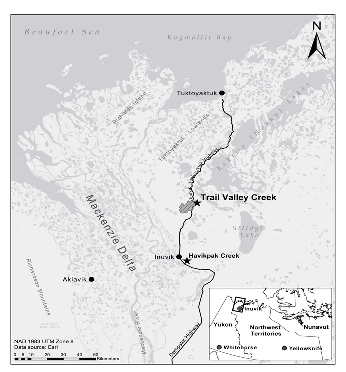
- **Computationally Highly Expensive**
- Are existing models performing as per expectations?
- Are we fine tuning free model parameters too much to match observations?
- Are the models reliable in different scenarios?
- **Can we constrain models? OR limit fine tuning?**

Model performance: A comparative case study

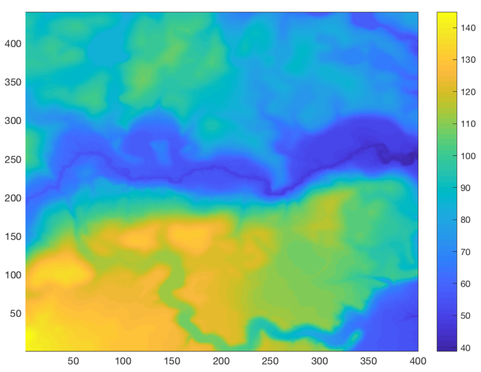
- **Used SnowModel (SM) (Liston *et. al.*) to reproduce the results of Essery *et. al.* (1999)** model
- Computed vegetation-wise snow water equivalent (SWE) and sublimation
- Model run: 11^{th} Sep 1996 to 8^{th} May 1997



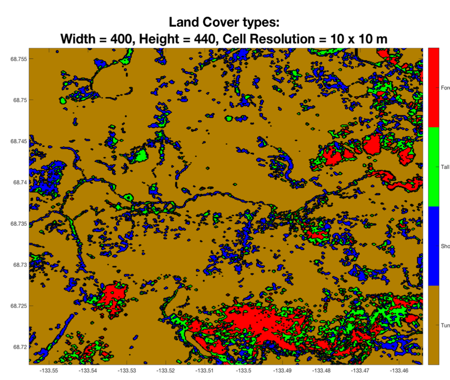
SnowModel (SM)



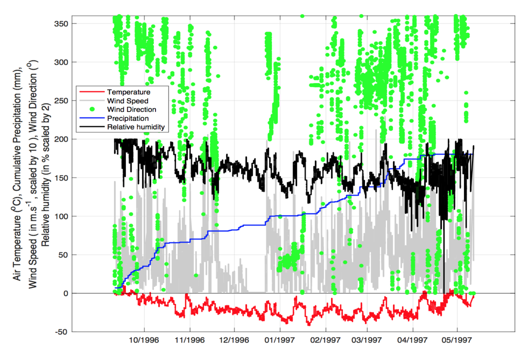
Location (TVC)



DEM (10m×10m)

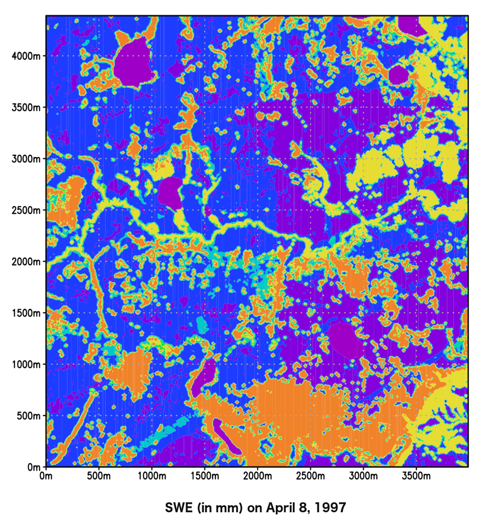


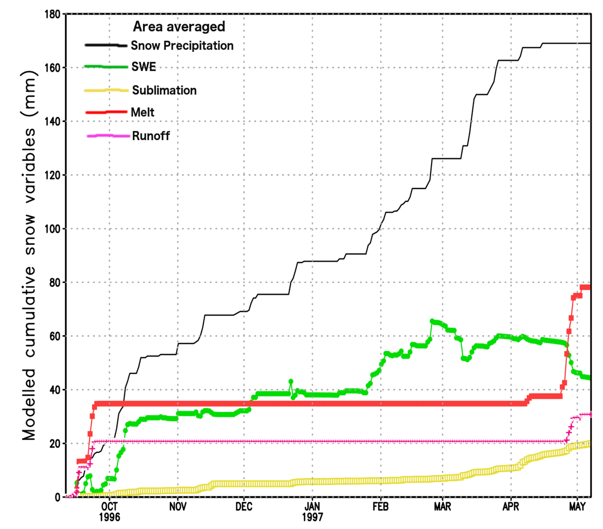
Vegetation classes

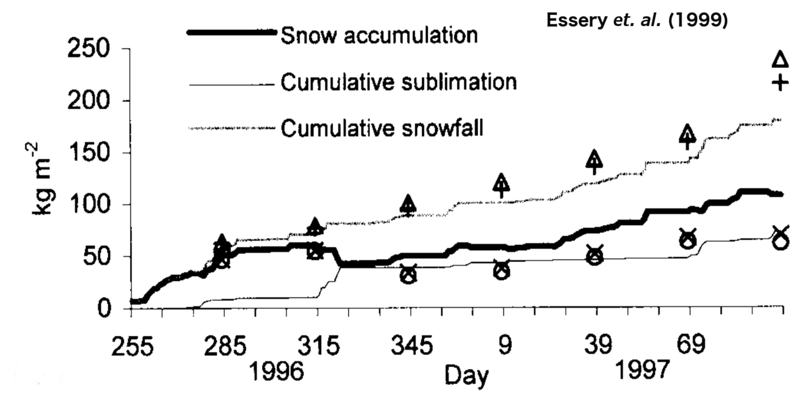


Forcing Met. data

Results







Comparison of model results:

Vegetation	Sublimation (mm)		SWE (mm)		C_v	
	Essery	SM	Essery	SM	Essery	SM
Open Tundra	71 (40%)	22 (13%)	62 (36%)	40 (23.5%)	0.42	1.025
Shrub Tundra	85 (47%)	8 (5%)	215 (120%)	146 (86%)	0.09	0.038
Forest	47 (26%)	8 (5%)	237 (132%)	148 (87%)	0.08	0.04

Comparison of SnowModel results with snow survey of 23^{rd} April 1997:

Vegetation	SWE (mm)		Std. Dev.		C_v	
	Survey	SM	Survey	SM	Survey	SM
Open Tundra	86	33	27	38	0.31	1.15
Shrub Tundra	219	142	42	5.5	0.19	0.038
Forest	215	145	49	6	0.23	0.041

Discussions

- Model predictions are different
- For ex, Essery *et. al.* predicted much more sublimation and transport compared to SM
- More focus is needed on modeling methodologies
- Demand for a more unified approach which help constrain many sub models
- A deeper understanding of snow-wind interaction

Based on

1. Liston G. E. & Elder K. A., Am. Met. Soc. (2006) 1259-1276.
2. Pomeroy J. W., *et. al.*, J. Glaciol. (1993) **144** 165-192.
3. Essery R., *et. al.*, Hydrol. Process. (1999) **13** 2423-2438.
4. Lehning M., *et. al.*, Hydrol. Process. (2006) **20** 2111-2128.

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