Development of Improved Forward Models for Assimilation of Snow Properties into Land Surface Models

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In conjunction with

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Outline

- Introduction

  Importance of snow in (terrestrial) water budget studies

  Satellite remote sensing of snow

  Model-based physical approaches for prediction of snow properties

- Forward Emission Models for Snow Microwave T_b Retrival

  DMTR, LSMEM, MEMLS

- Models Testing and Validation

  NASA's CLPX experiment

  Sensitivity analyses, emission models vs CLPX and AMSR-E data

- Conclusions, Challenges, and Future Work

  Multi-sensor, multi-platform, multi-scale snow T_b assimilation - twin experiment set up

Introduction: importance of snow in water budget estimates

- **Snow cover extent (SCE) and water equivalent (SWE) are key factors in land-atmosphere feedbacks**
- **As much as 90% of annual streamflow is snowmelt driven in the western US**
- **Operational large-scale estimates of SCE and SWE would likely enhance the accuracy of NWP**
- **Improved NWP forecasts would also benefit flood forecasting and drought monitoring.**
- **In situ observations are unable to temporal and spatial variability of snow processes**

Introduction: satellite remote sensing of snow

Snow Cover Extent (SCE)

- Visible wavelength sensors (GOES, AVHRR, MODIS etc)
- Cloud-free conditions required
- Lack of any information about water storage

Snow Water Equivalent (SWE)

- Passive microwave sensors (SSM/I, AMSR-E etc)
- Coarse spatial resolution
- Wet snow and metamorphism greatly affect signal

Introduction: satellite remote sensing of snow

- Potential exits for improved retrieval of SWE at large-scales from space-borne microwave radiometry. Challenging because microwave T_b derives from surface, snow pack, vegetation, and atmosphere

- SWE retrieval theory:
  - dielectric constant of frozen water differs from liquid form
  - snow crystals are effective scatterers of microwave radiation (snow density, grain size, stratigraphic structure and liquid water)
  - deeper snow packs --> more snow crystals --> lower T_b

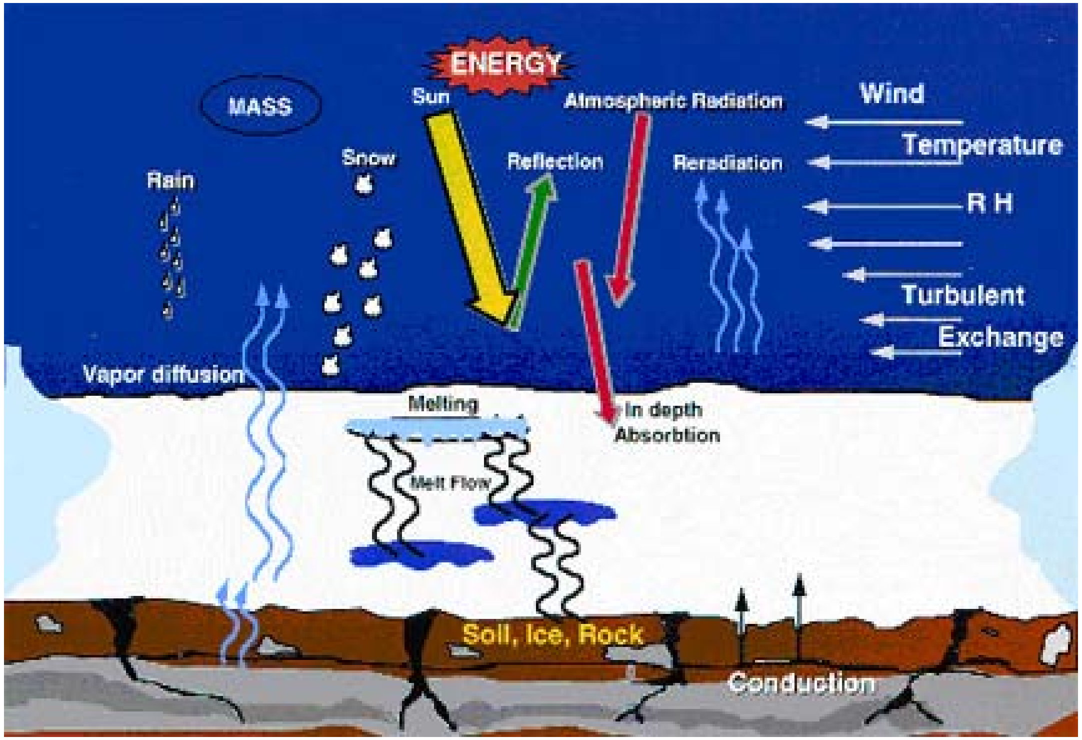
- Direct assimilation of T_b is a challenging problem - requires comprehensive land surface microwave emission model.

Introduction: physical models of snow properties

- Additional information about snow properties can be obtained by mass/energy balance snow models
- Uncertainty in forcing data and/or model parameters
- Nonlinearity and scale of modeled processes

Introduction: physical models of snow properties

Example: SNTHERM (SNow THERmal Model)



Output : snow depth, profiles of snow temperature, water content, density, grain size

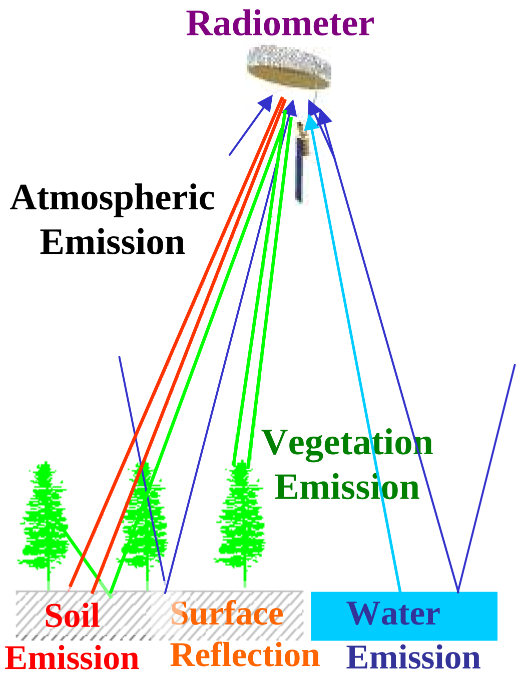
Research Questions

- Can a forward model of surface microwave emission be developed that is capable of providing realistic brightness temperatures for snow covered areas,
- Can the inputs for the forward model be provided by operational observations and/or physical snow model output, and
- Is the modeled/predicted T_b sufficiently accurate and useful for assimilation into operational NWP?

Forward emission models for snow Tb retrival

$T_b = F(\text{Atmos}\uparrow\downarrow, T_{veg}, T_{snow}, T_{soil}, \varepsilon_{snow}, \varepsilon_{soil}$, scattering albedo, optical depth)

- Processes needed for cold seasons:
  - frozen ground
  - snow covered surface
  - tall vegetation (snow or no snow).



Observed emission =
surface (snow/soil) emission + reflection
+ vegetation emission + attenuation
+ atmospheric emission + attenuation
+ water/ice emission + reflection

Forward emission models for snow Tb retrival

All Seasons LSMEM (Drusch et al., 2001, 2004; Gao et al., 2004)

- Calculates microwave emission from a surface partially covered with vegetation and/or snow
- Snow component based on the semi-empirical HUT emission model
- Treats snowpack as a single homogeneous layer
- Dielectric constants of ice and snow calculated from different optional models
- Inputs include snow depth, density, temperature, grain size and ground temperature

DMRT (Tsang et al, 2000)

- Calculates Tb from a densely packed medium
- A quasi-crystalline approximation is used to calculate absorption characteristics with particles allowed to form clusters
- The distorted Born approximation is used to calculate the scattering coefficients
- Inputs include snow depth, snow temperature, fractional volume and grain size

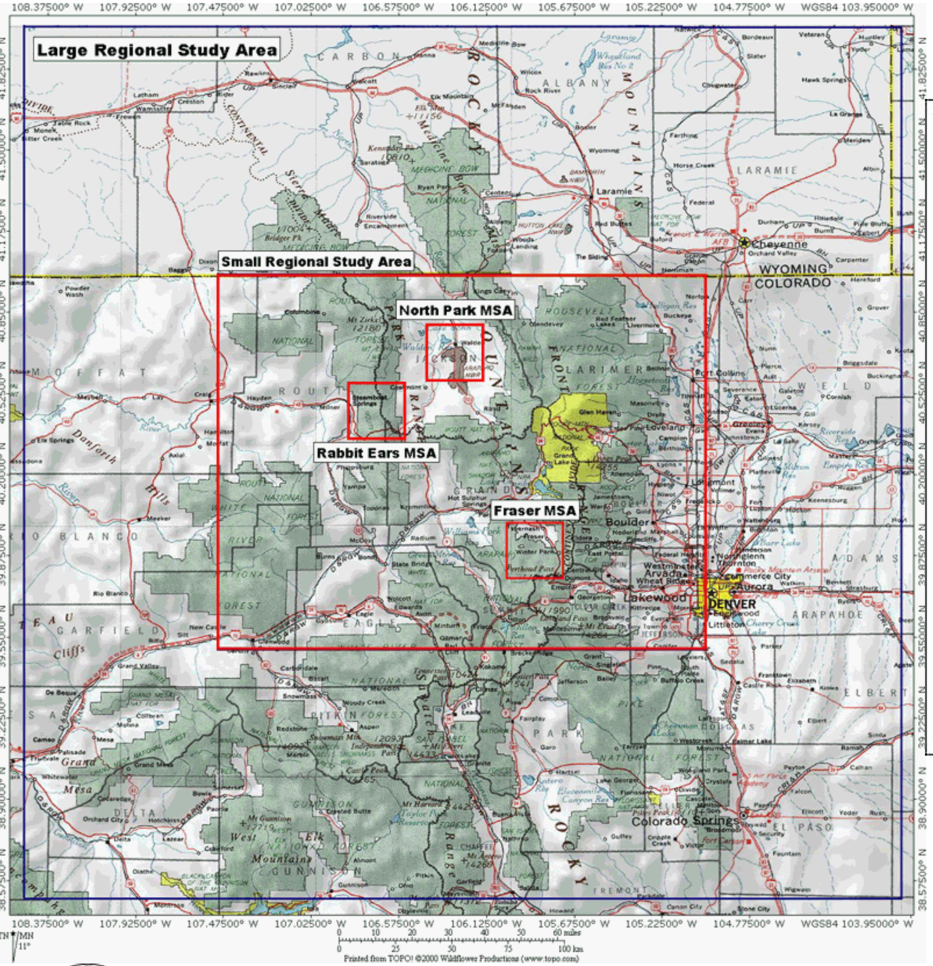
MEMLS (Metzler, 1998)

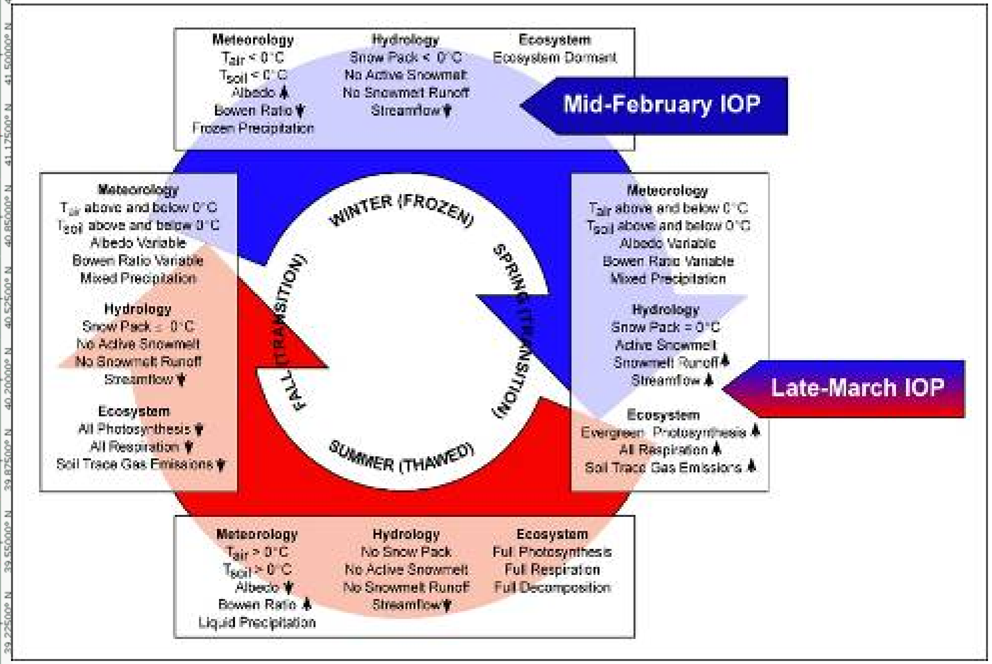
- Calculates Tb from a multi-layer snow medium
- The absorption coefficient is derived from snow density, frequency and temperature
- The scattering depens on snow density, frequency and correlation length
- Inputs include snow depth, temperature,density, ground temperature and correlation length
- So far successfully validated only for dry snow conditions

Models Validation and Testing

CLPX Cold Land Processes Field Experiment Plan

NASA Land Surface Hydrology Program - Cold Land Processes Working Group



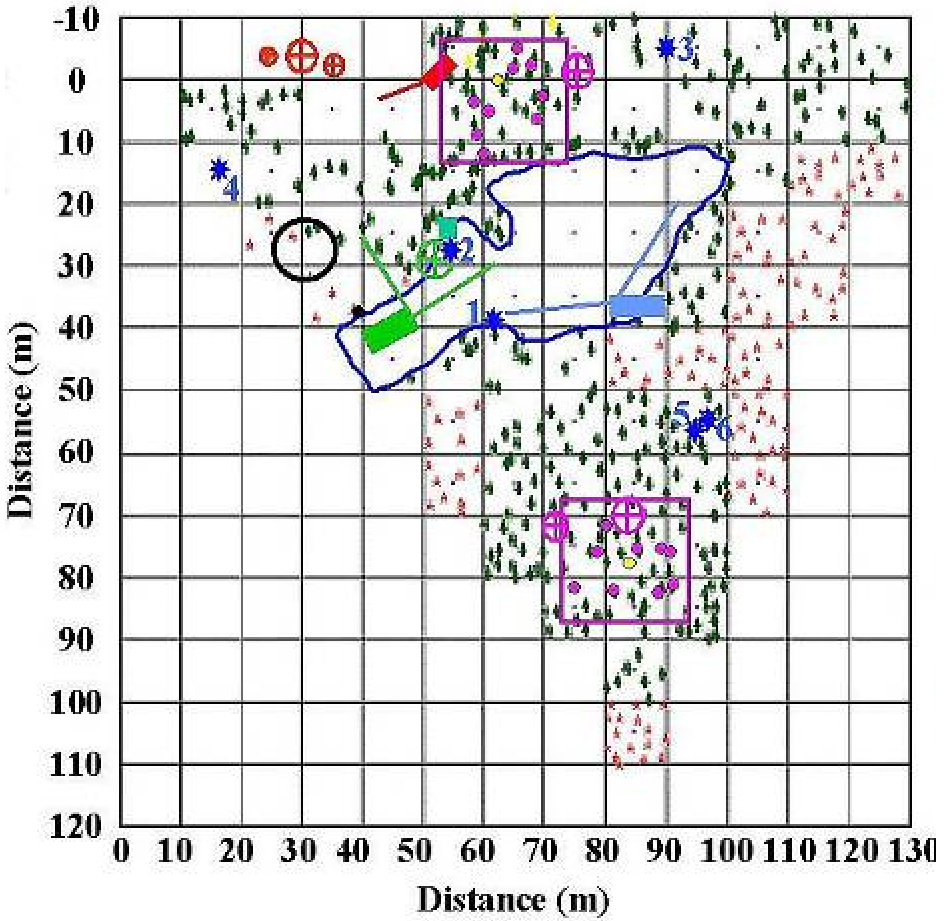


Models Validation and Testing

Validation with CLPX Observations

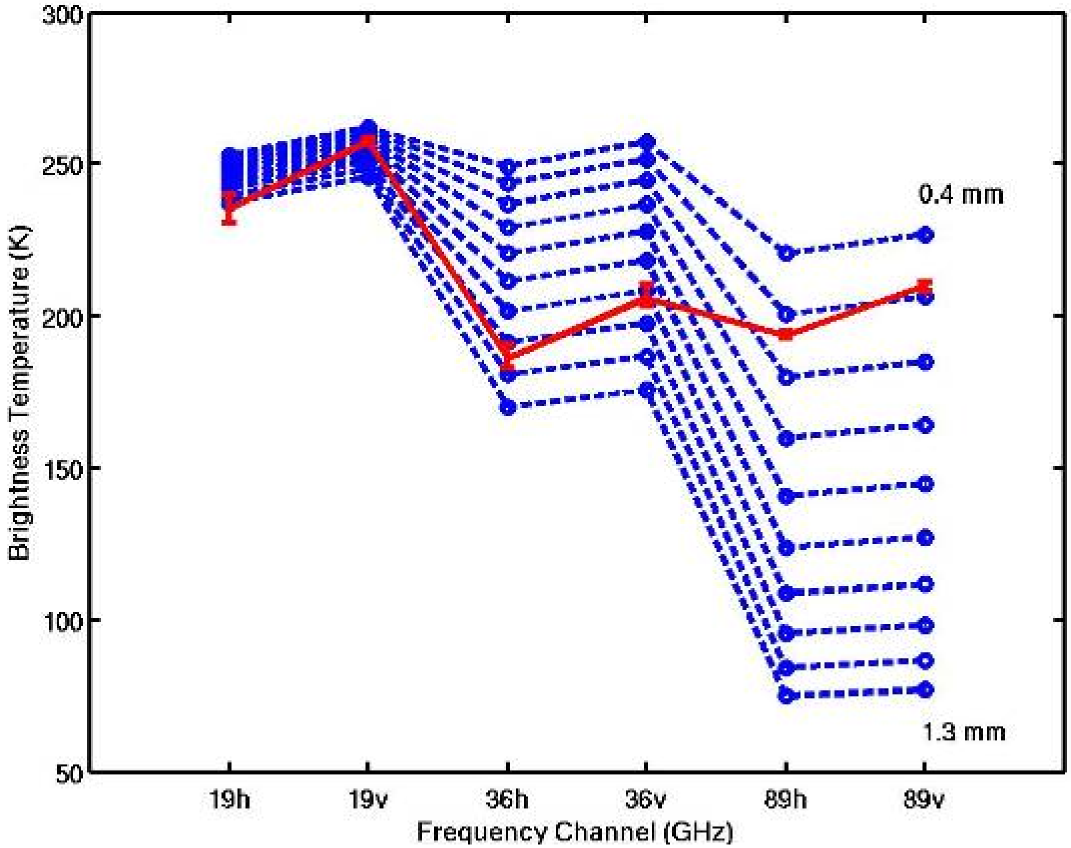
- Ground-Based Microwave Radiometer (GBMR)
- Dense Snow Pit measurements
- 12-13 Dec 2002 & 19-24 Mar 2003
- Snow on bare ground (no vegetation)
- Assume snow measurements representative of entire LSOS (100 x 100 m)

LSOS Layout



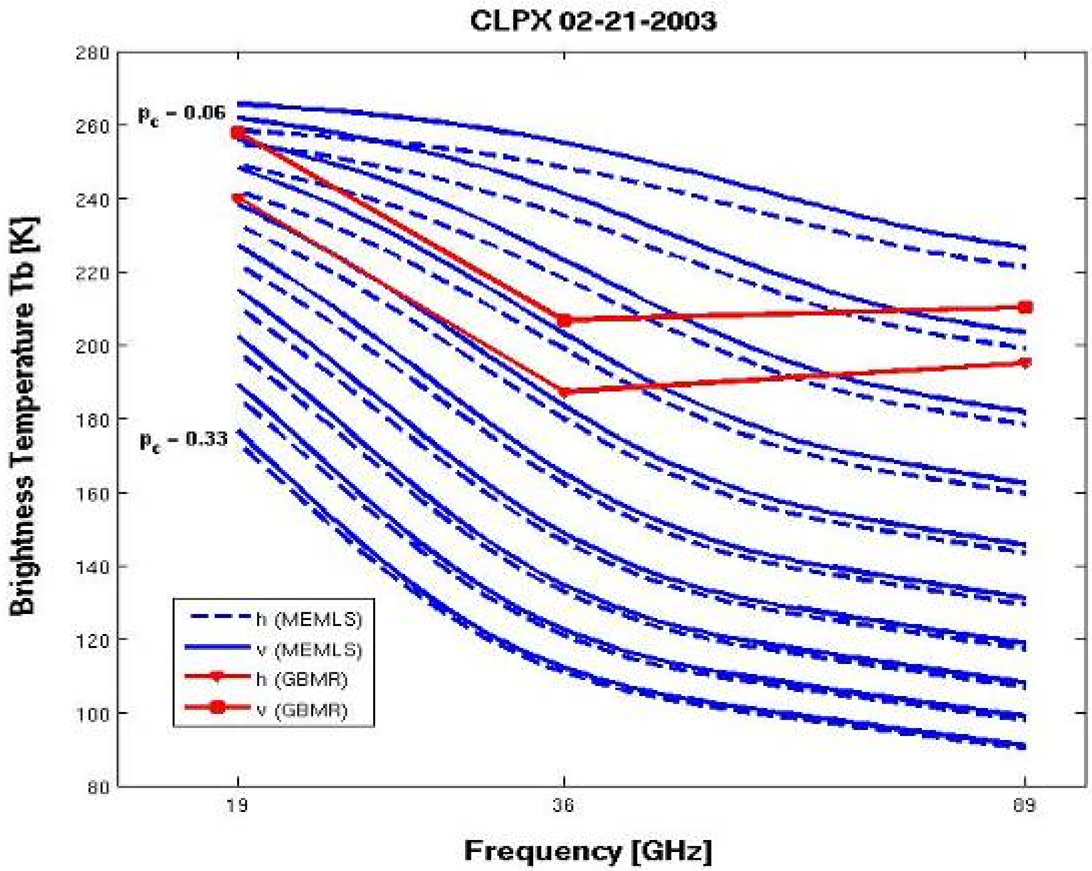
Models Validation and Testing

- Microwave emission from full snow coverage at 55°
- AS-LSMEM was run for different grain sizes to capture observed stratigraphy
- Strong dependence of results with assumed grain size



Models Validation and Testing

- Microwave emission from full snow coverage at 55°
- MEMLS was run for different correlation lengths to capture observed stratigraphy
- Strong dependence of results with assumed correlation length



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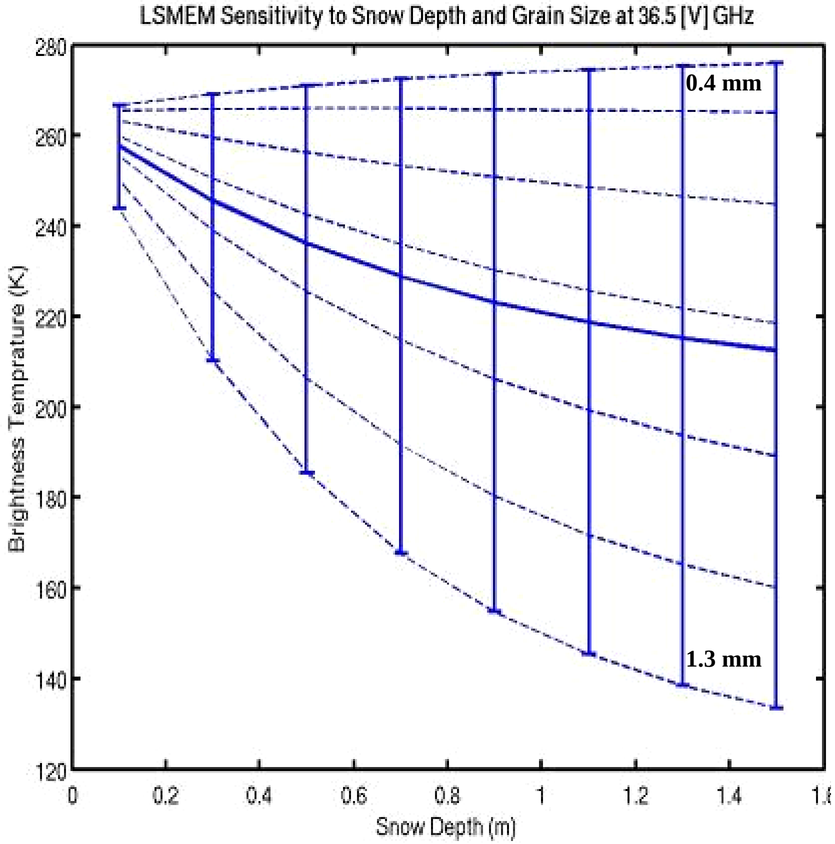

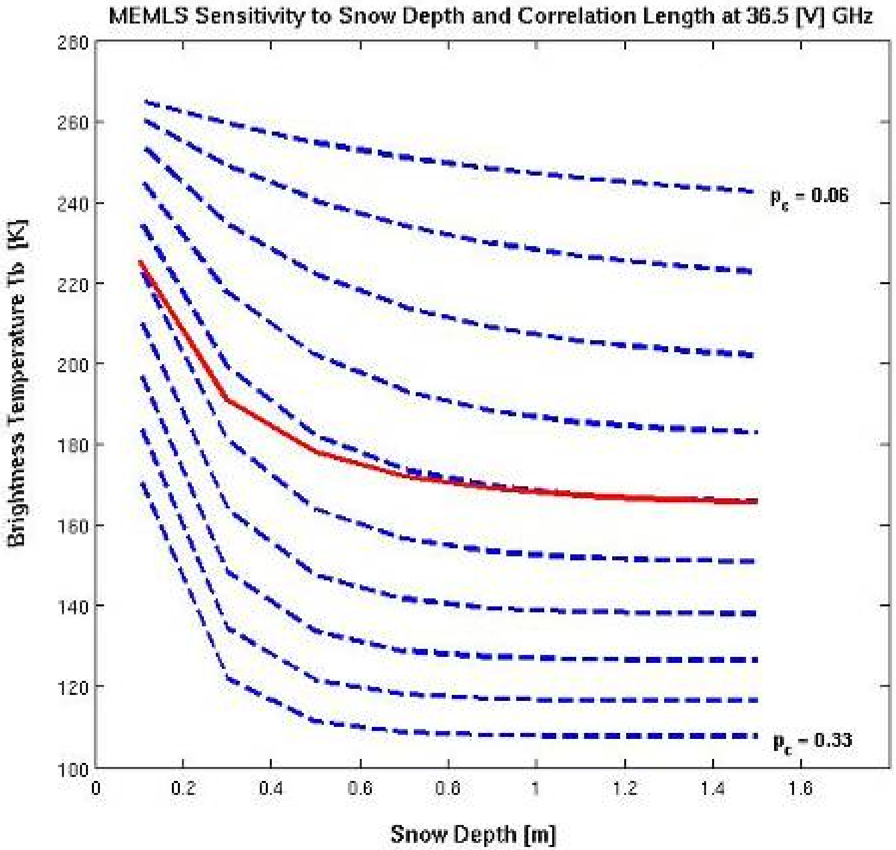

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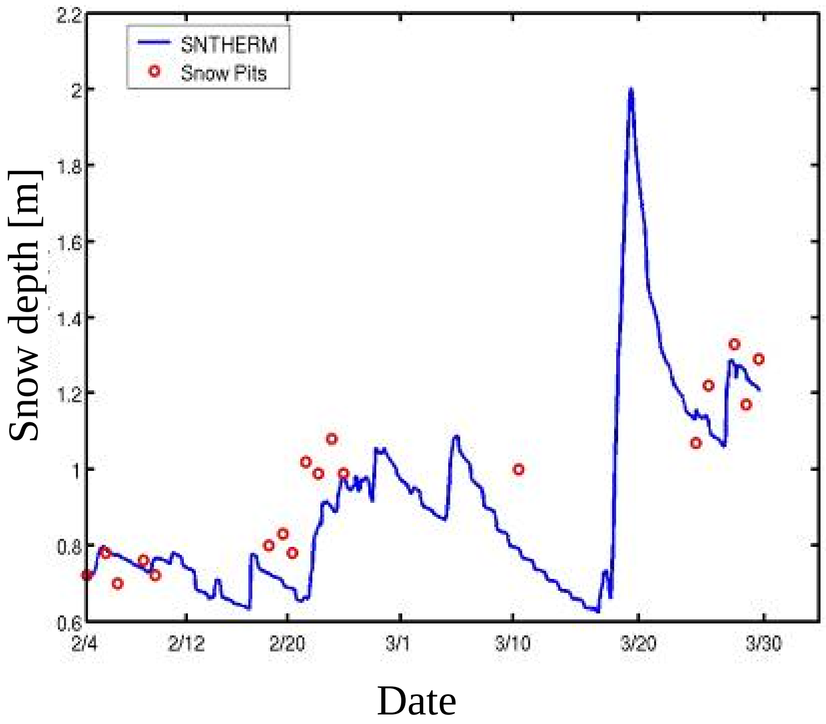
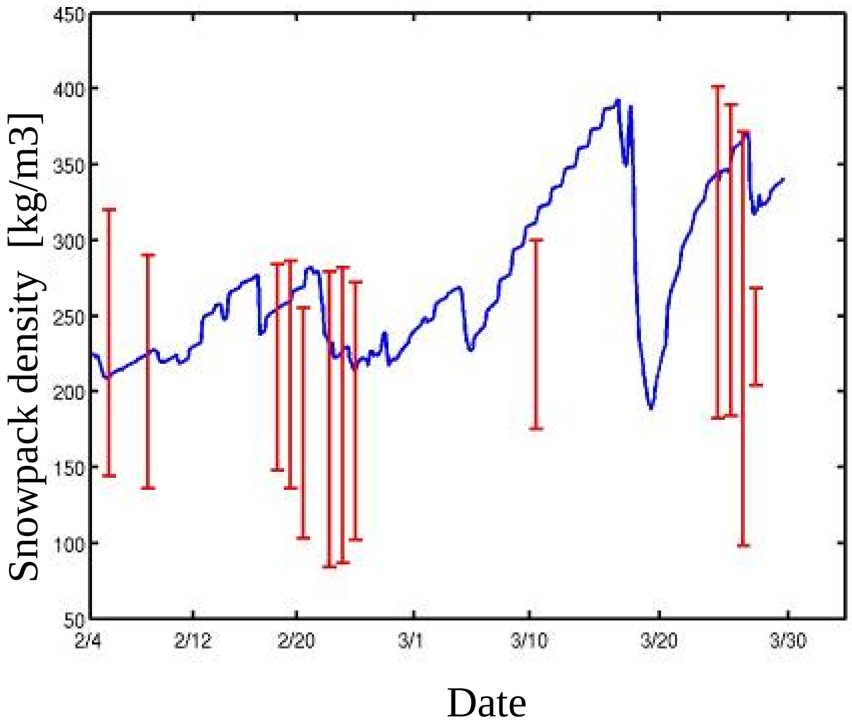
Models Validation and Testing

Validation of SNTHERM at CLPX Snow Pits, Feb-March 2003





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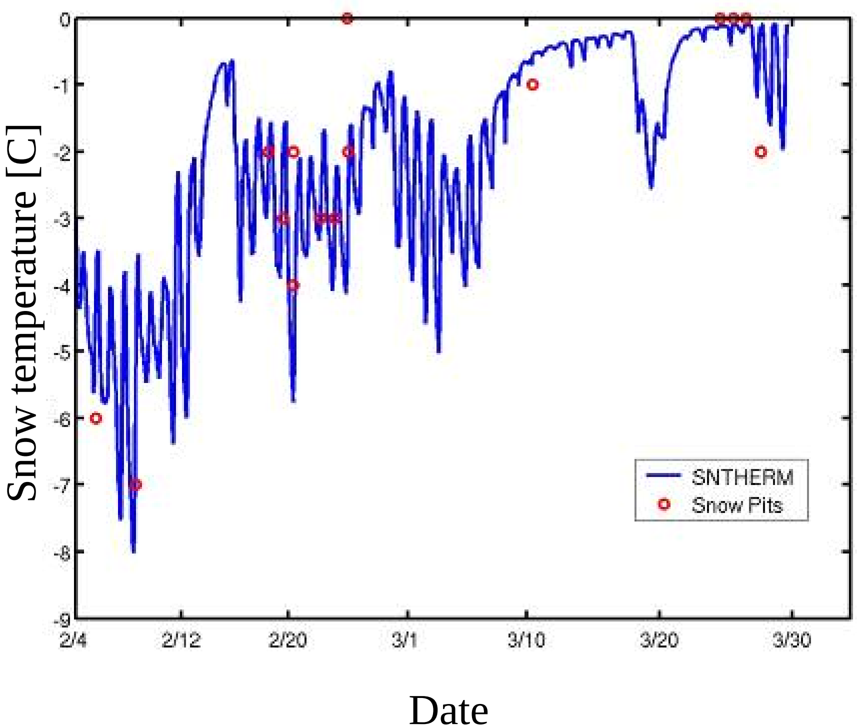
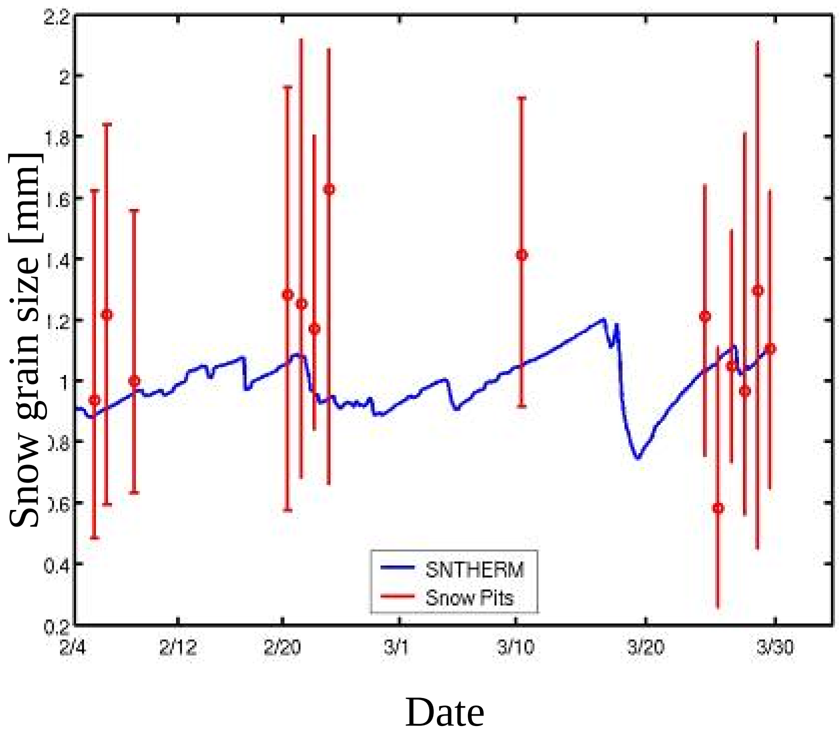




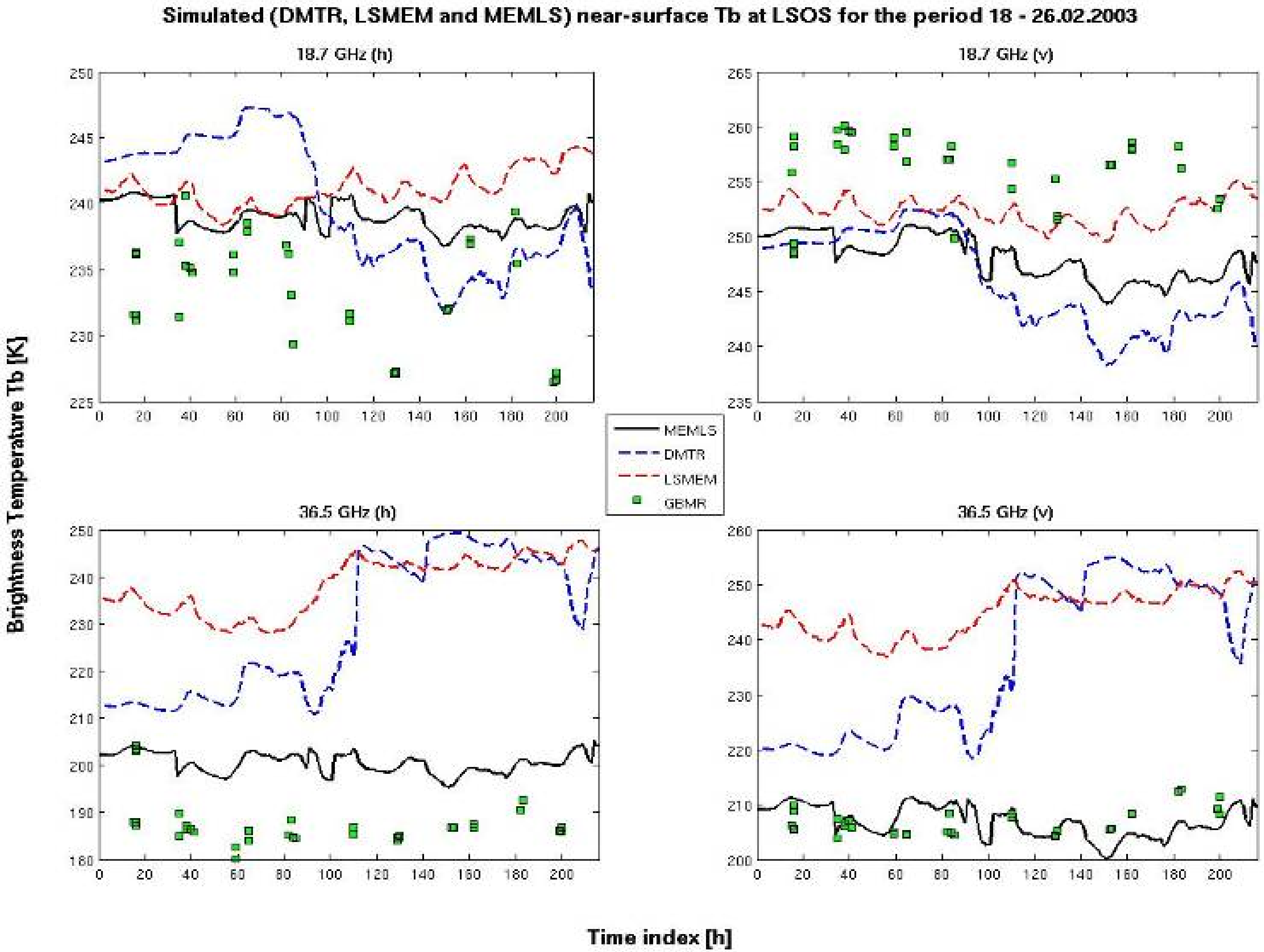
Models Validation and Testing

Can the inputs for a forward model be provided by physical snow model output to obtain realistic Tb estimates?

- force AS-LSMEM, DRTM, MEMLS with outputs from SNTHERM
- compare estimated Tb with GBMR and AMSR-E measurements at 18.7 and 36.7 (h/v) Ghz

Assumptions: single snow layer, dry snow

Models Validation and Testing



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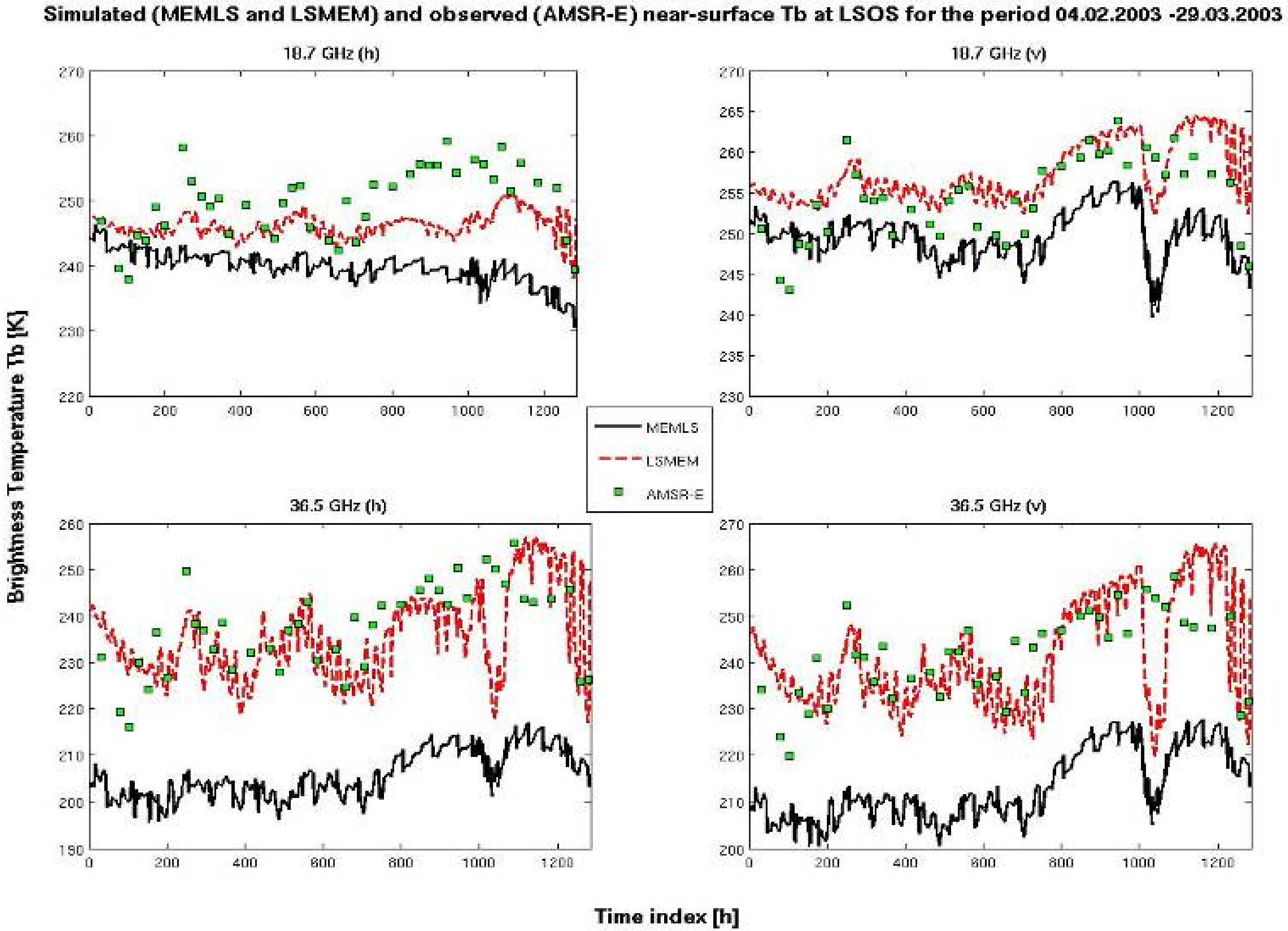


Conclusions, challenges and future work

Potentials

- There is great potential is for estimating snow Tb by forward emission models

- Assimilating satellite Tb could improve snow estimates in land surface models at variety of spatio – temporal scales ---> improved water budget estimates

- Data assimilation offers the framework to:
  - optimally combine forward emission models and remote sensing observations of snow Tb
  - account for the limitations of both by error structure description

Challenges and Future Work

- Understanding of the error structure of forward emission models, sensors, etc, including how they vary in time and space

- Data assimilation of snow Tb observations

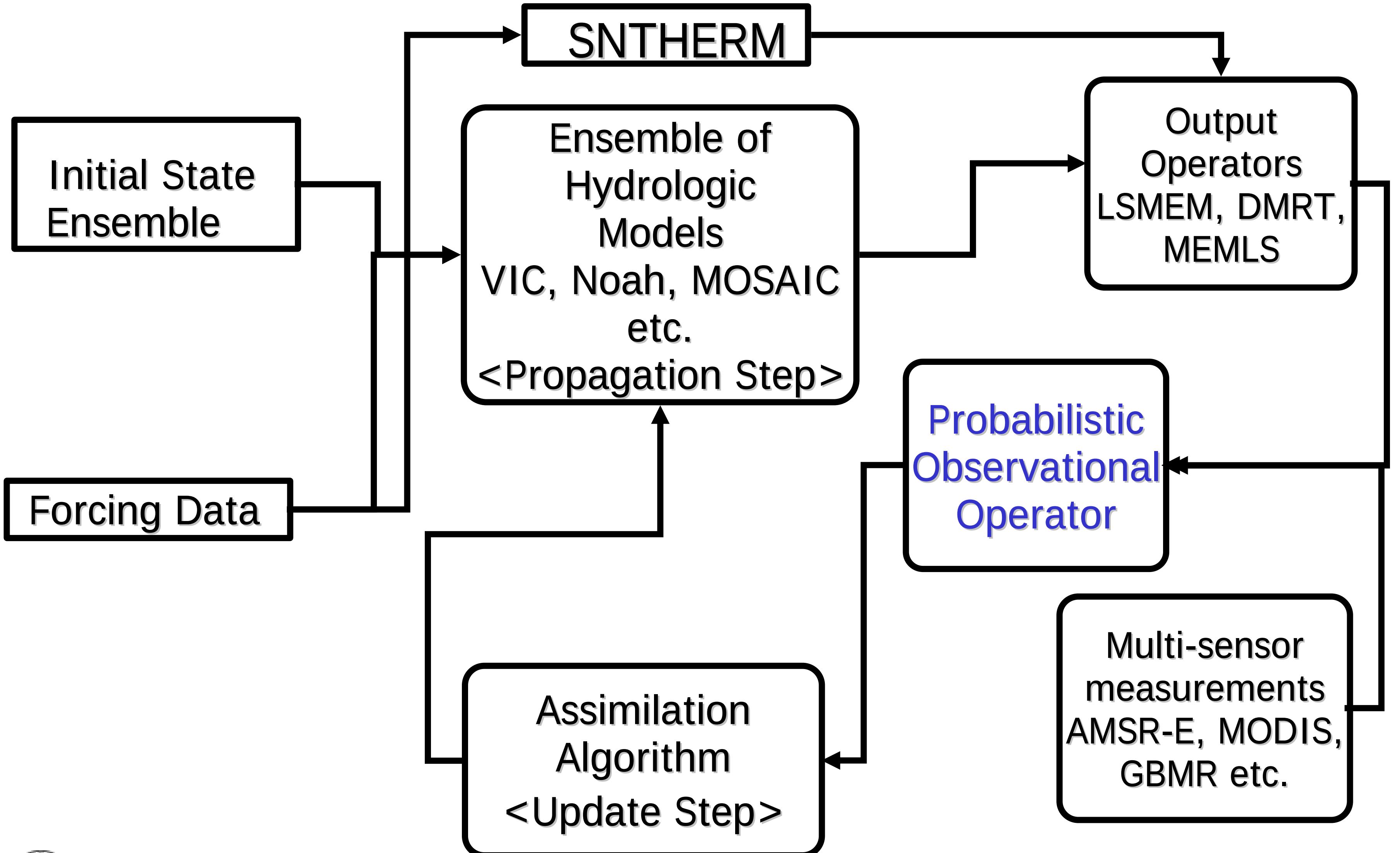
- Improving forward emission models

Conclusions, challenges and future work

Twin experiment: multi -model, multi-scale, multi sensor snow Tb data assimilation

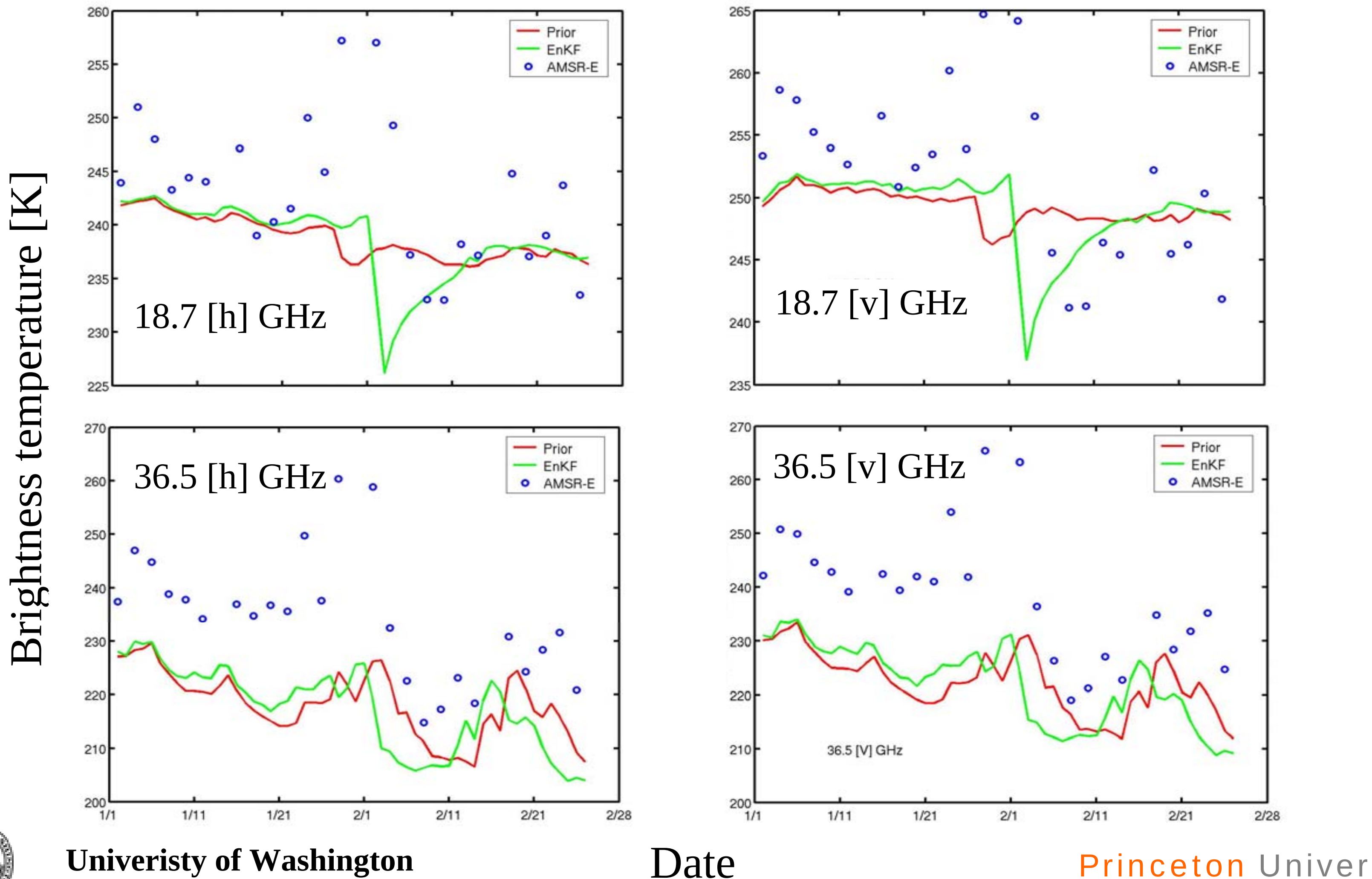
- **Generate "snow reality" with SNTHERM at multiple spatio-temporal scales**
- **Force an ensemble of forward emission models with SNTHERM output**
- **Compare the above estimates of Tb with multi-sensor measurements**
- **Derive observational operators by quantizing error structure using flexible pdf estimators (copula models, mixture models)**
- **Assimilate multi-sensor measurements into Noah LSM and/or multiple land surface models**
- **Update snow characteristics, combine them (Bayesian model mixture) and compare with SNTHERM "snow reality"**

Conclusions, challenges and future work

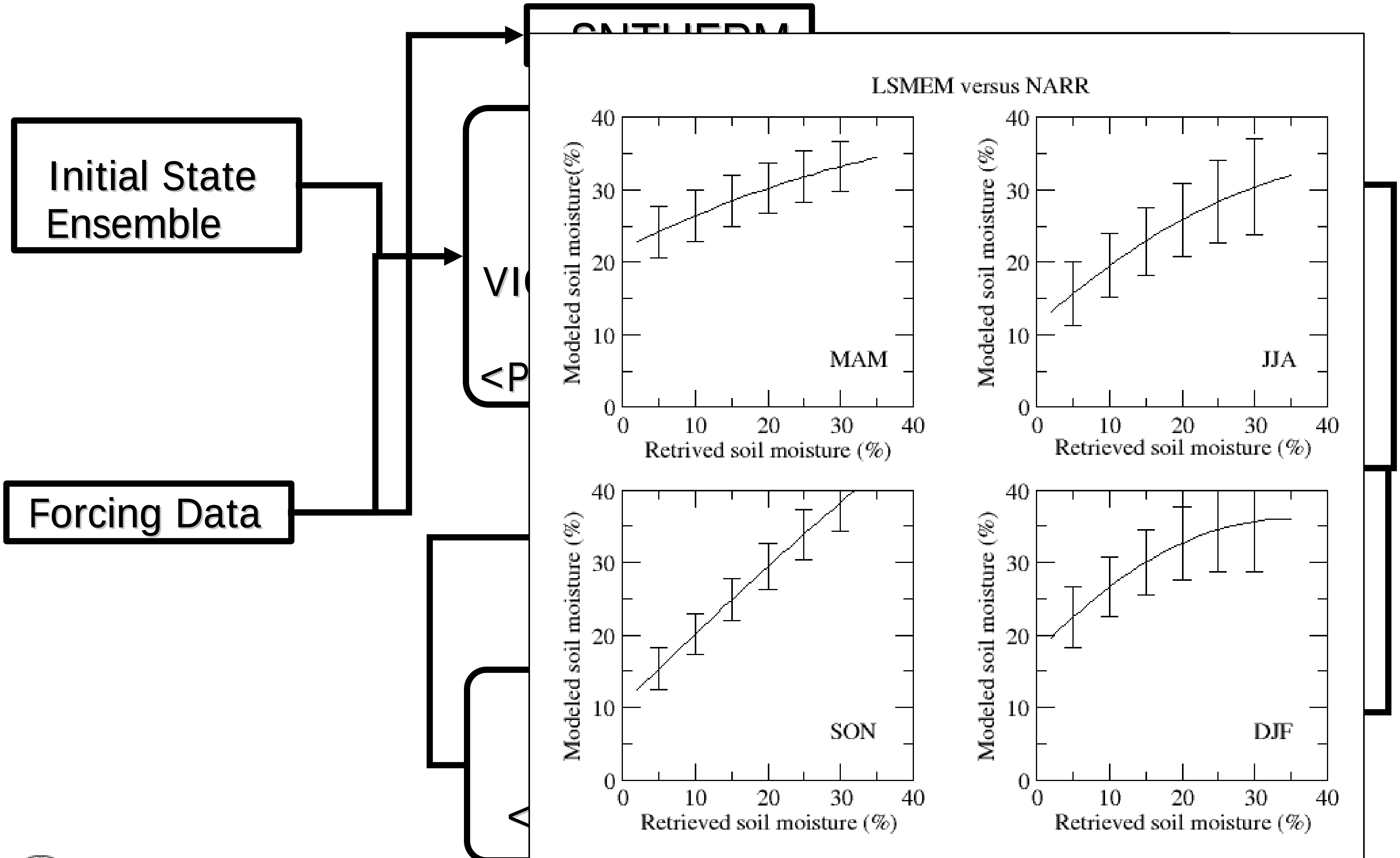


Conclusions, Challenges and Future Work

Simulated (SNTHERM/LSMEM before and after assimilation) and observed (AMSR-E) high-altitude brightness temperatures over the Stanley Basin (43.60 N, 114.67 W)

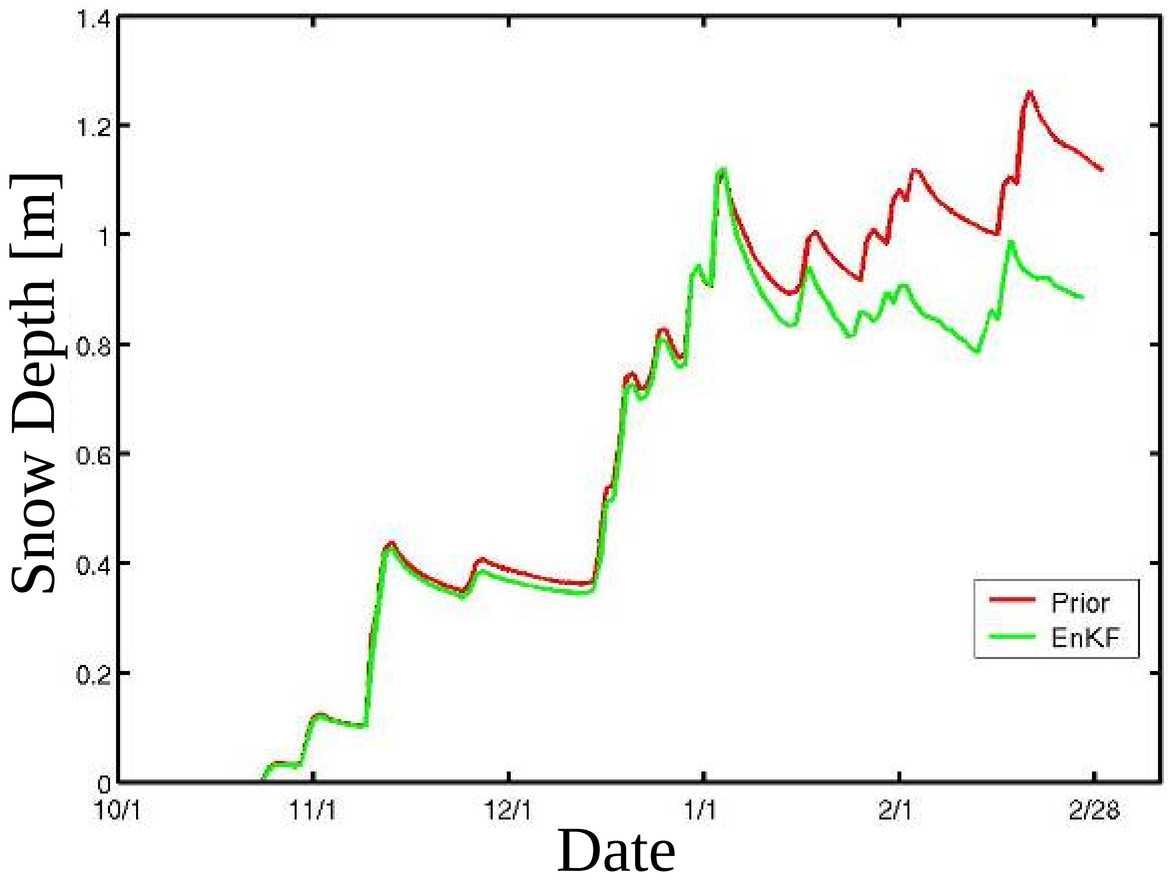


Conclusions, challenges and future work



Conclusions, Challenges and Future Work

Simulated snow depth, before (prior) and after (EnKF) assimilation in the Stanley Basin (43.60 N, 114.67 W).



The End

Probability of a White Christmas (snow depth 1" or more)