Development of improved forward snow microwave emission models

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Research goals

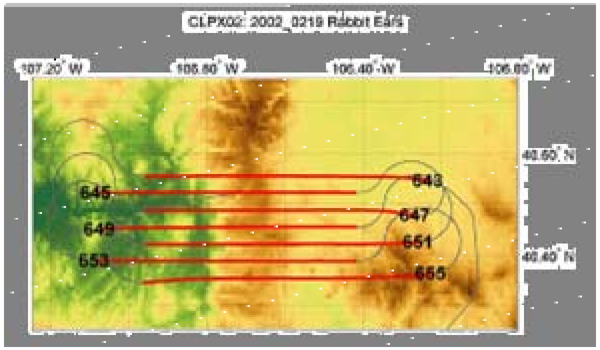
- Testing and validation of different snow microwave emission models
- EM models coupled to a snow hydrology model
- Error characterization for both models and observations: very important for data assimilation
- Sensitivity and spatial scaling of model predictions
- Development of framework for assimilation of satellite microwave brightness temperatures

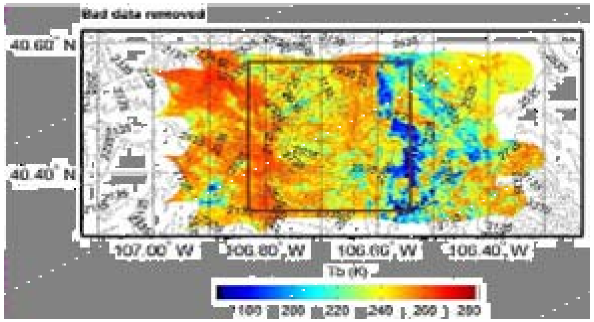
Outline

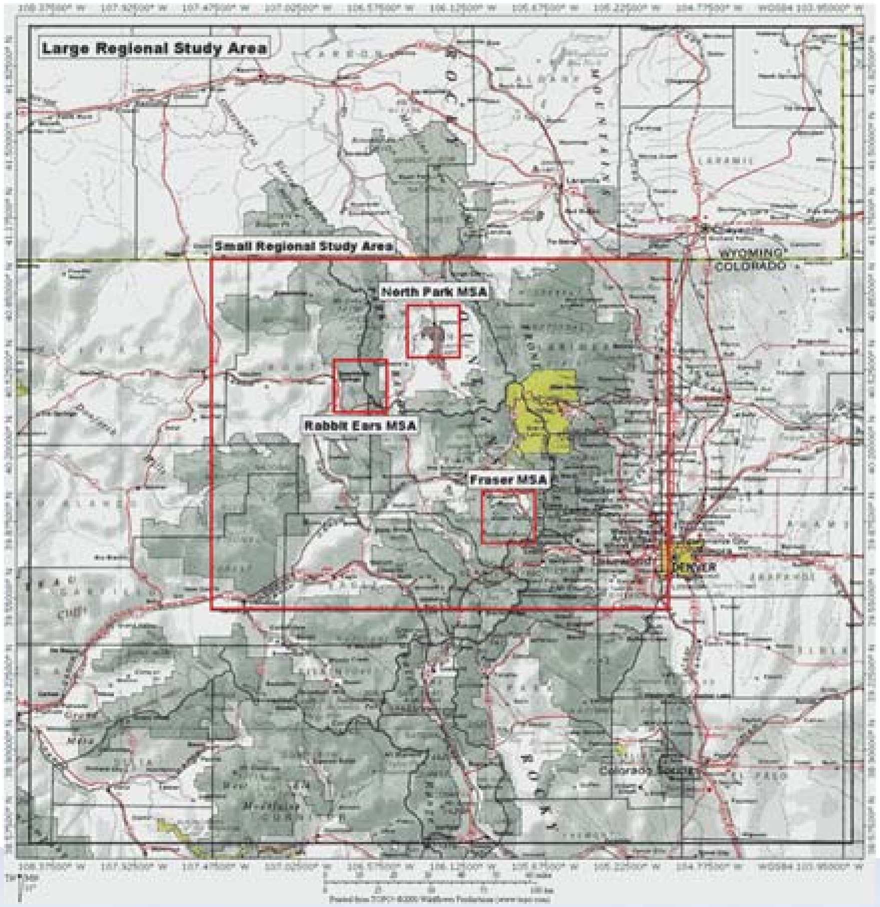
- Model description and experimental design
  - Microwave emission and hydrologic models
  - CLPX observation datasets
- Inter-comparison of model predictions with AMSR-E satellite observations
- Bayesian Model Averaging – Multi-model estimation
- Sensitivity of model predictions to errors in snow parameters and surface heterogeneity
- Spatial scaling behavior of satellite observations and model predictions

Cold Land Processes Experiment (CLPX)

- Multi-sensor and multi-scale measurement campaign over Colorado during winters of 2002 and 2003



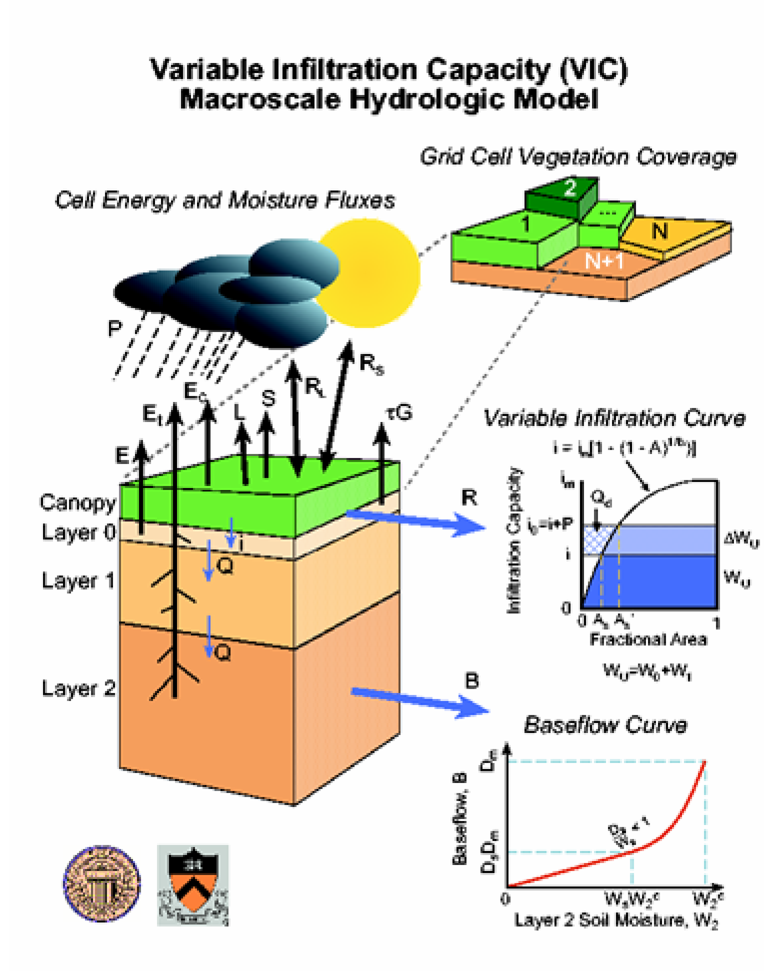




- Satellite (AMSR-E)
- Aircraft (PSR) – 3 sites (25x25 km)

Snow hydrology model

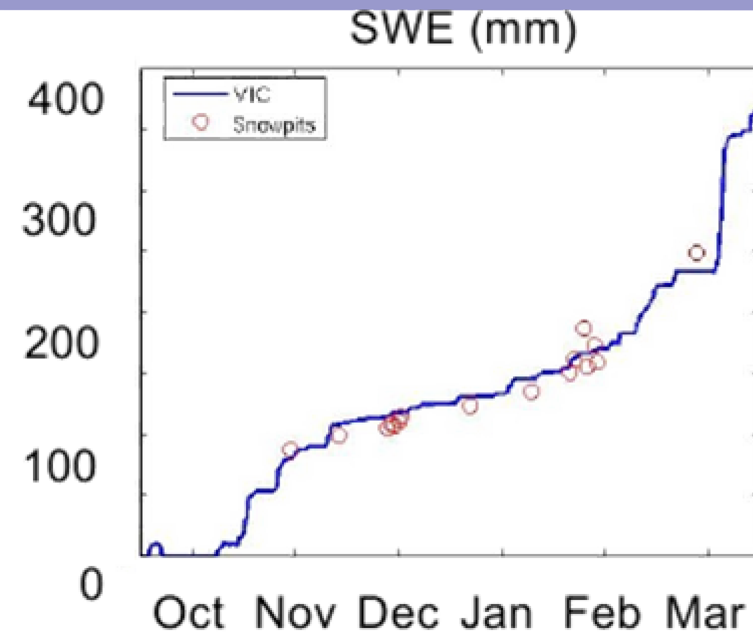
- Variable Infiltration Capacity (VIC) model
- Forced with precipitation and air temperature
- Essentially one-layer snow mass and energy balance model
- Accounts for snow interception processes, densification, melting/refreezing
- Grain growth algorithm added for this evaluation

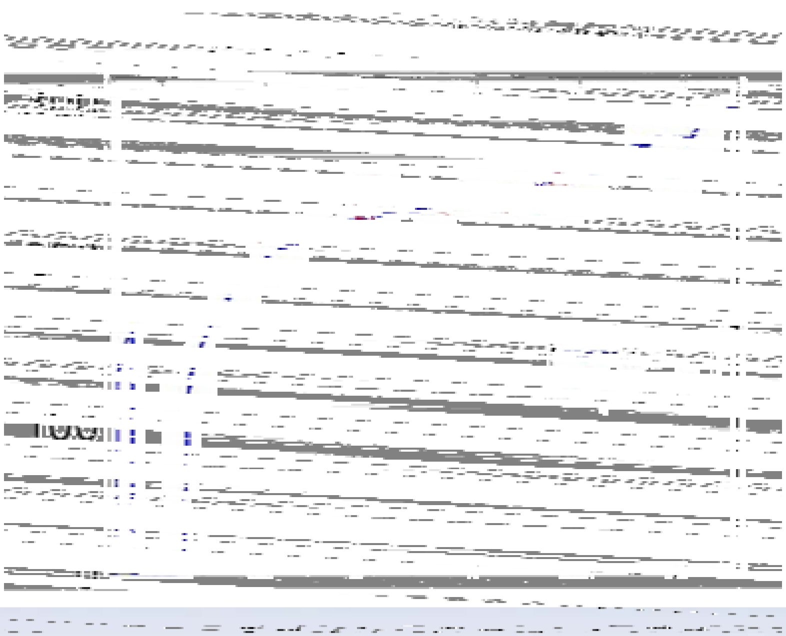


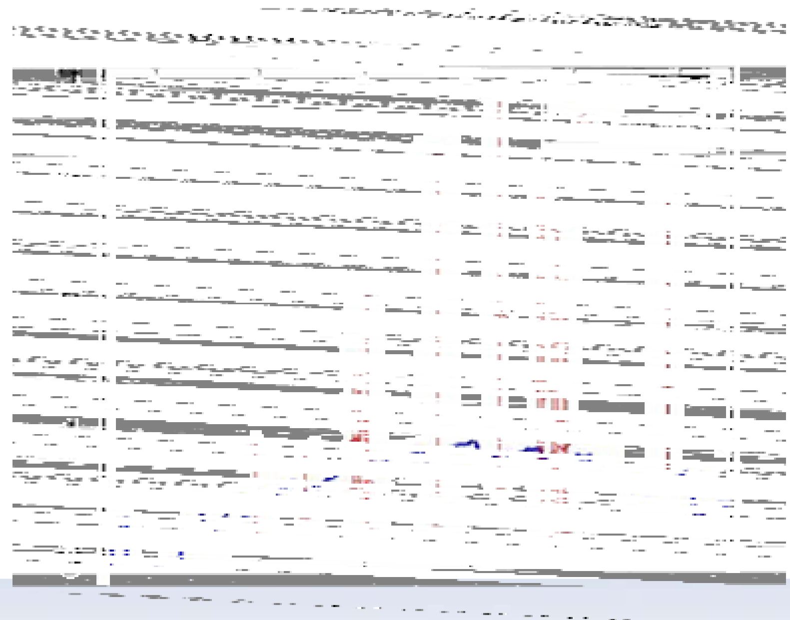
$$\frac{\Delta d}{\Delta t} = \frac{G}{d} D_{es} C_T \left| T_s - T_g \right|$$

VIC validation

- Ability of model to reproduce snow properties given accurate meteorological forcings
- Validation with point measurements over a 100x100 m clearing (LSOS)



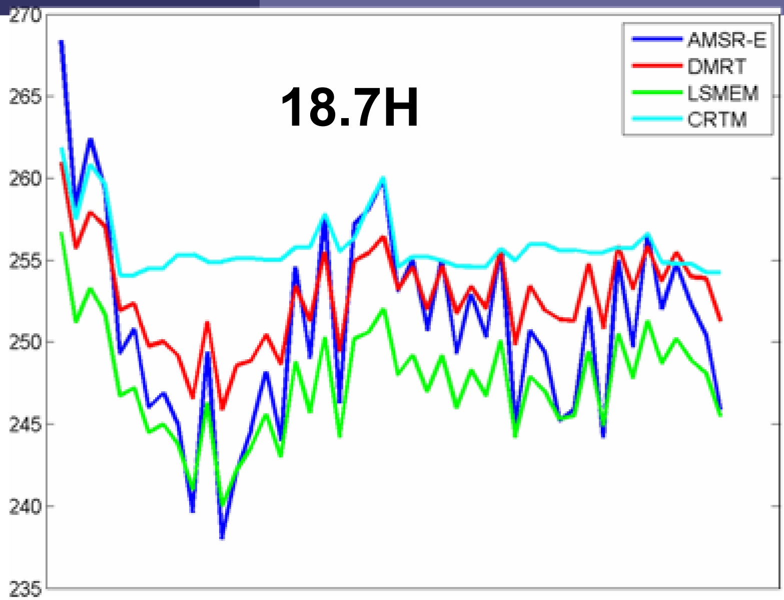


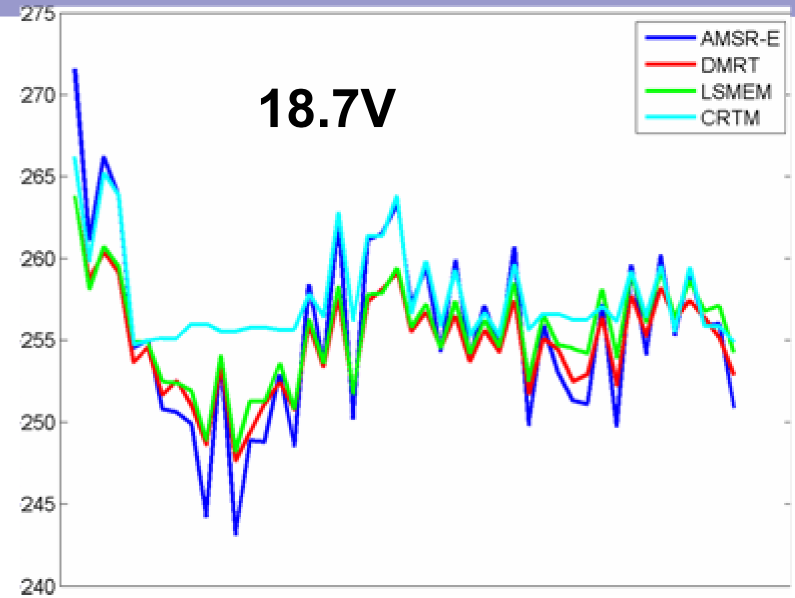


Snow microwave emission models

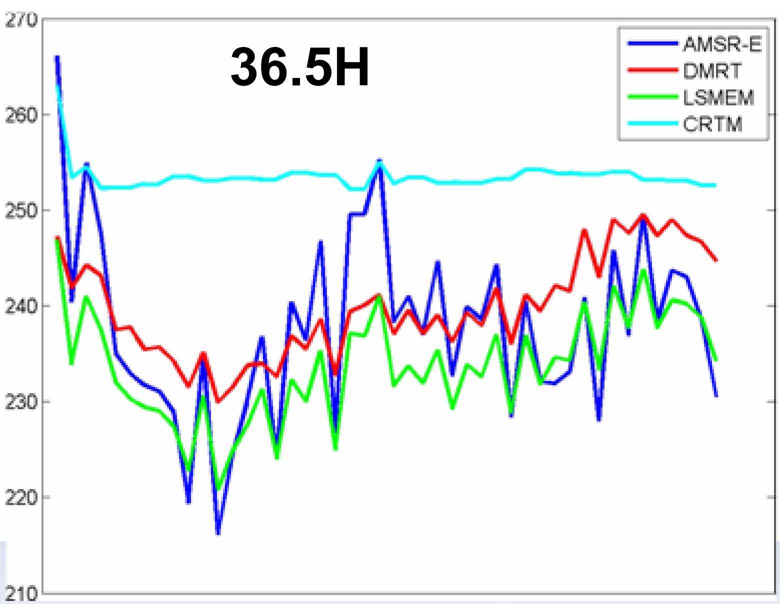
- All Season LSMEM (Drusch et al 2004)
  - based on semi-empirical HUT model
  - assumes mostly forward scattering
- DMRT (Tsang et al 2000)
  - accounts for collective particle scattering
  - distorted Born approximation to calculate scattering coefficients
- CRTM (Weng et al 2001)
  - based on dense media theory
- MEMLS (Wiesmann and Mätzler 1999)
  - multi-layer snowpack
  - scattering coefficients determined empirically

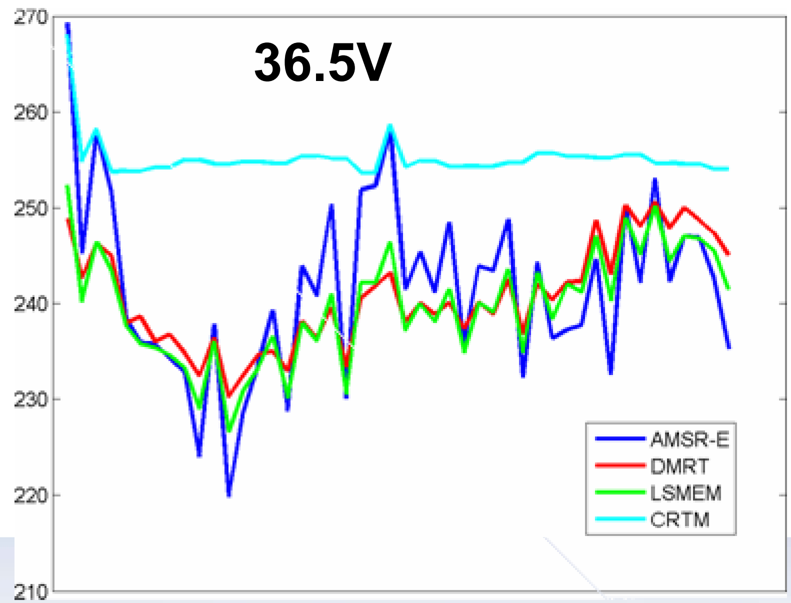
T_B time series at Fraser (CLPX)





February 2003 (both ascending and descending orbits)



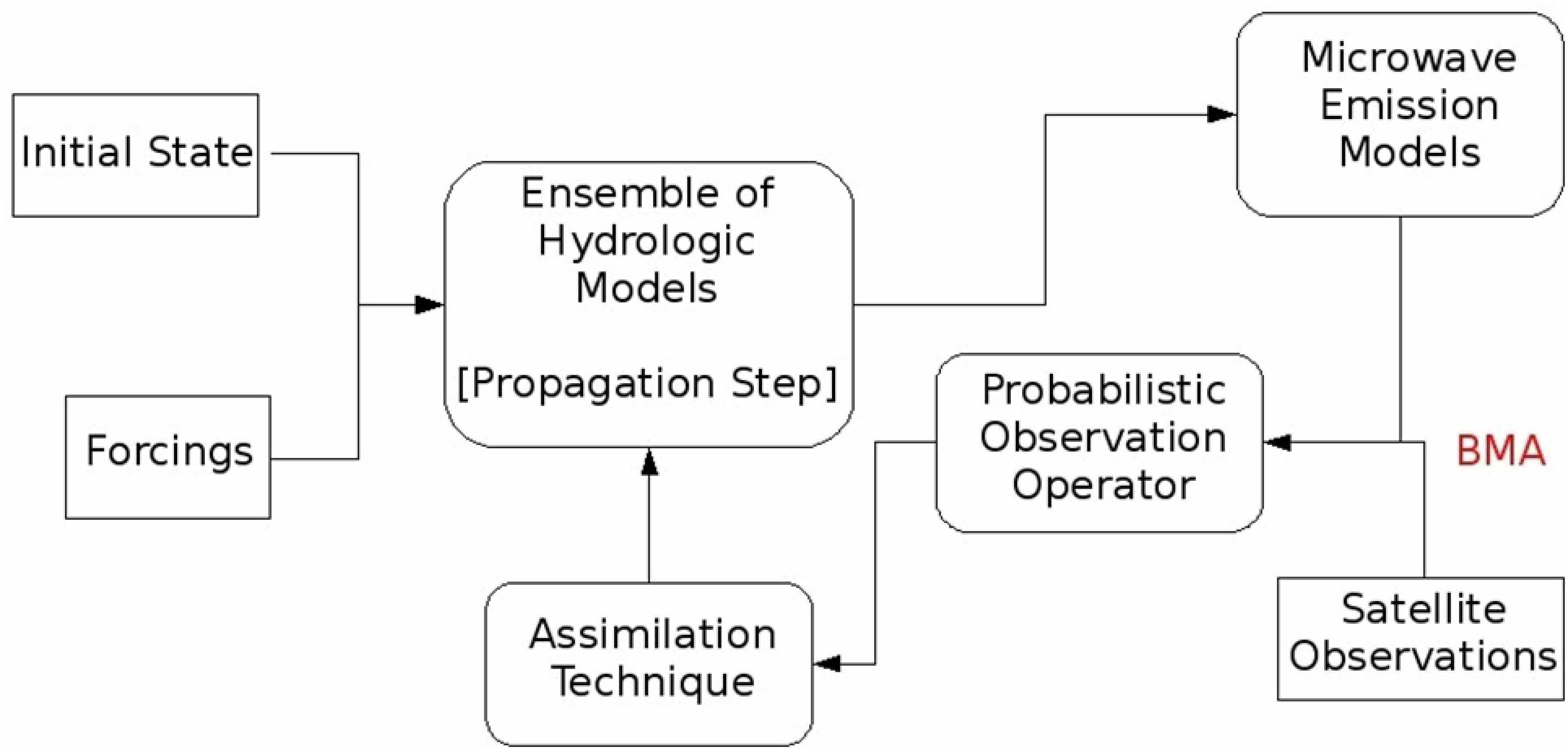


Model-predicted T_B correlations with AMSR-E observations

- Models perform reasonably well (except CRTM) for lower frequency
- Performance diminishes for higher frequency
  - snow grain size effects
  - different penetration depth

Frequency Model	18.7 Ghz Horiz.	18.7 Ghz Vert.	36.5 Ghz Horiz.	36.5 Ghz Vert.
DMRT	0.97	0.98	0.63	0.7
LSMEM	0.98	0.97	0.88	0.86
CRTM	0.71	0.85	0.44	0.51

Multi-model assimilation framework



Bayesian filtering

Bayesian Filtering:

Prior state, $x_{k|k-1}$

$$p(\mathbf{x}\,|\,\mathbf{z}) = \frac{p(\mathbf{x},\mathbf{z})}{p(\mathbf{z})} = \frac{p(\mathbf{x})\,p(\mathbf{z}\,|\,\mathbf{x})}{p(\mathbf{z})}$$

Posterior state, $x_{k|k}$

Observational operator:
Measure of uncertainty
in observation given state (or output)
(by Gaussian mixture)

(1) Integration (construct the filter):

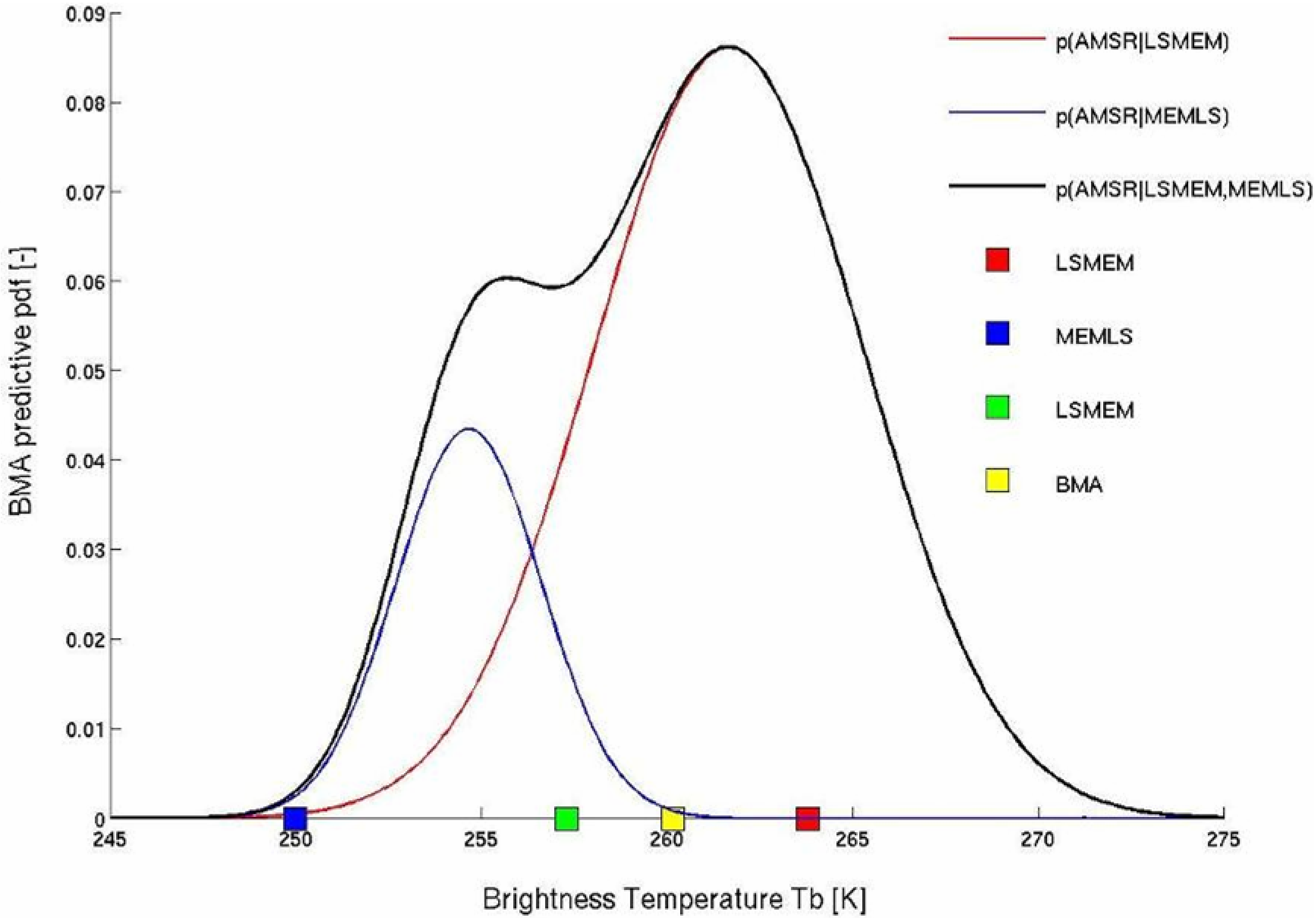
Monte Carlo (GEnKF, PF)

(2) Model the uncertainty in state give the observation

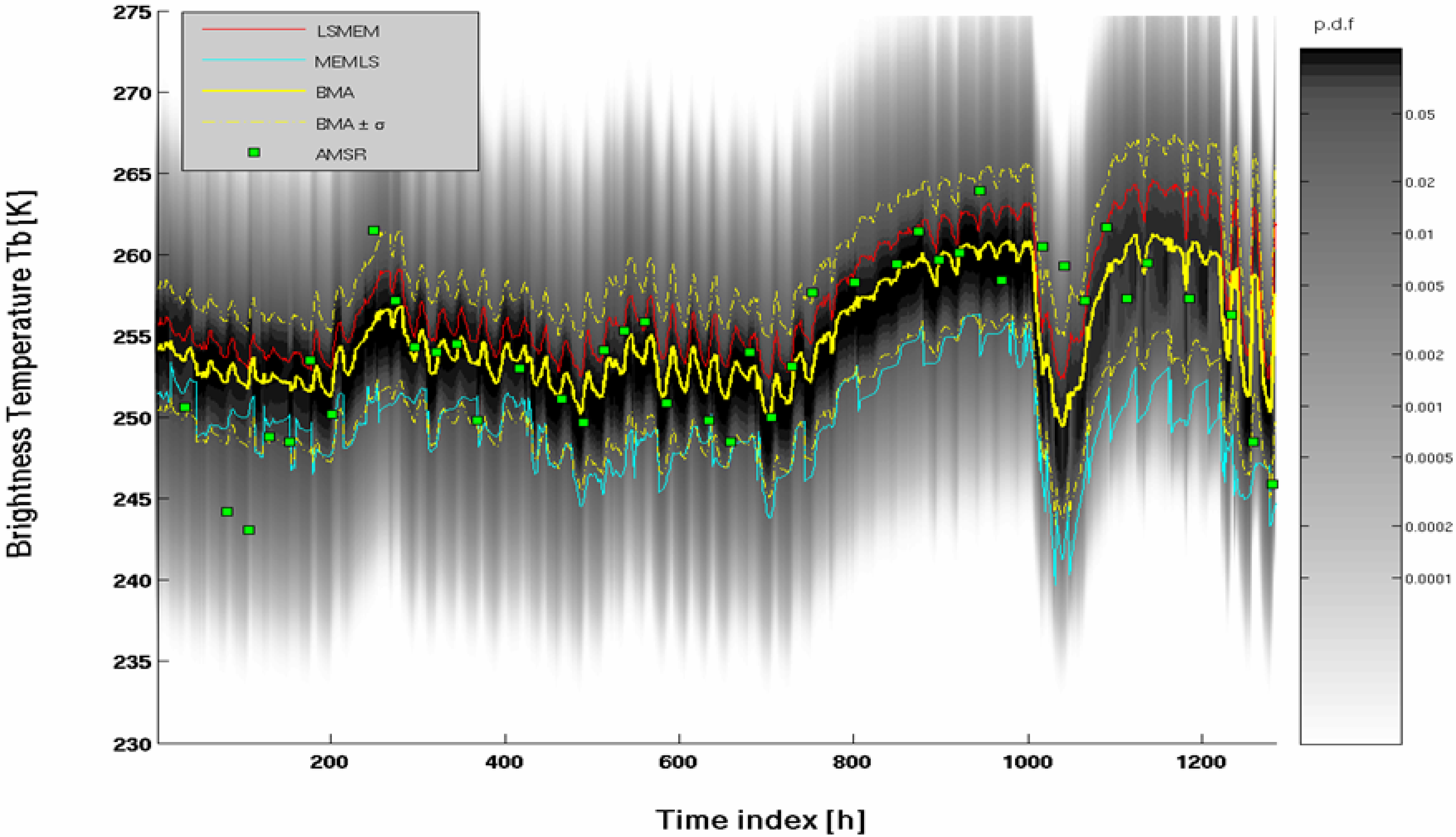
(Observational operator):

non-additive, non-Gaussian

Example of Bayesian estimation



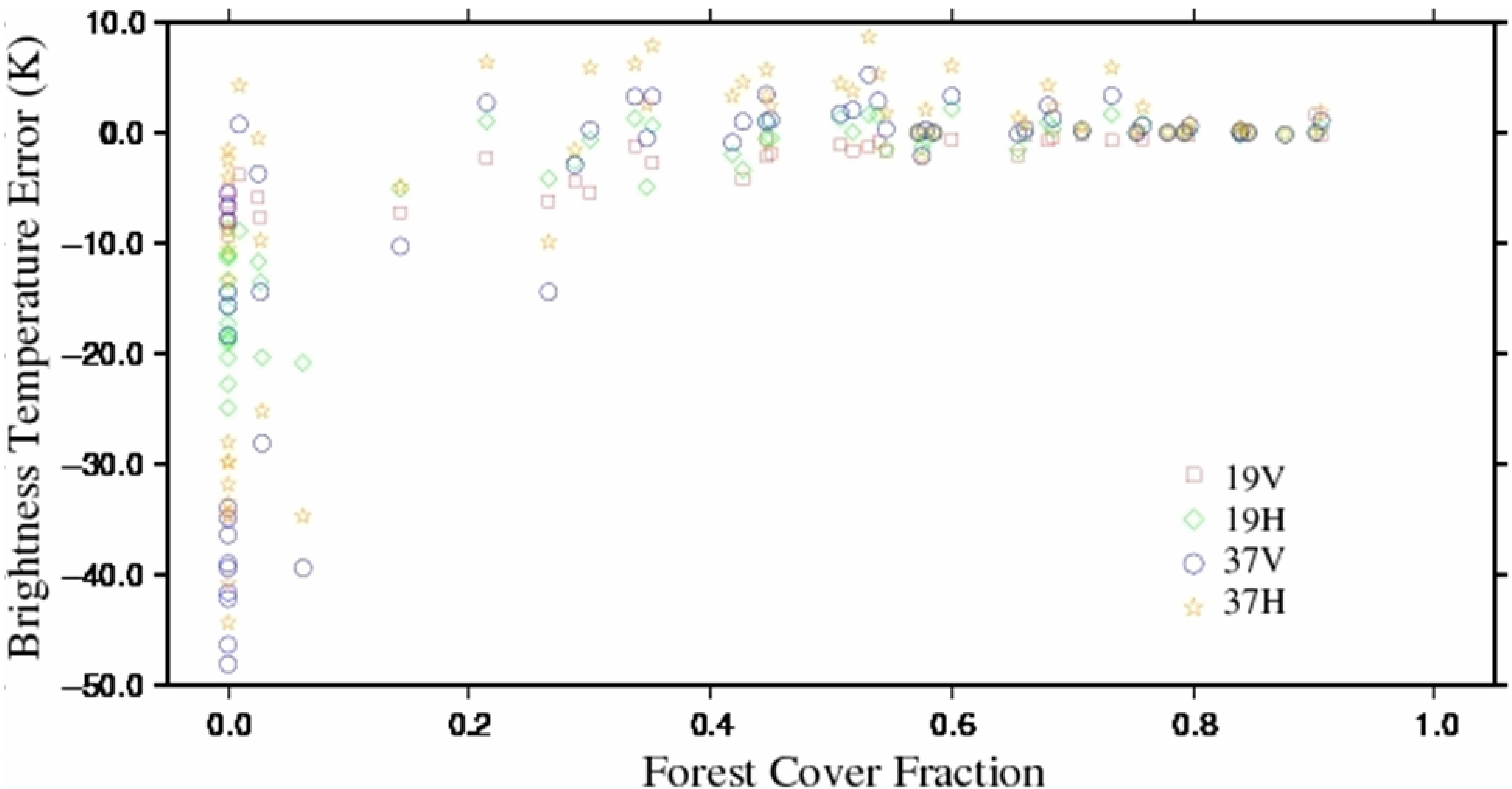
Multi-model Bayesian estimation example for Fraser



Some questions....

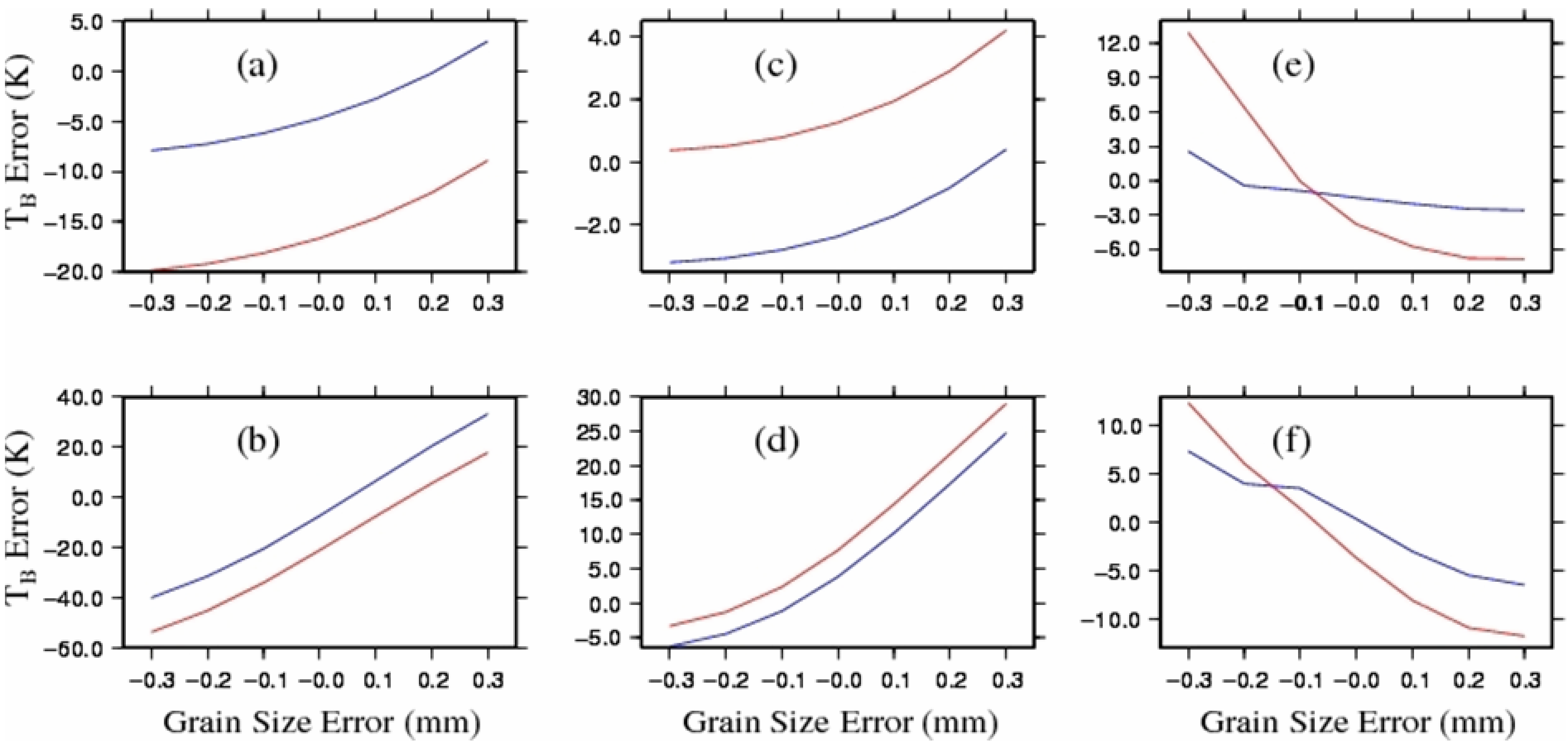
- How do we quantitatively represent the model errors?
- Examine the sensitivity of T_B prediction errors to errors in input snow parameters
- What are the effects of land features on radiance prediction errors?
- Evaluate dependence of T_B predictions on forest and snow cover fractions
- Can we say anything about the relationship between the coarse-scale satellite observations and the higher resolution model predictions?
- Take advantage of aircraft data over CLPX

T_B prediction error dependence on forest cover fraction



T_B prediction error sensitivity with snow grain size

Point Scale | Aircraft Scale | Satellite Scale



18.7 GHz

36.5 GHz

Horizontal

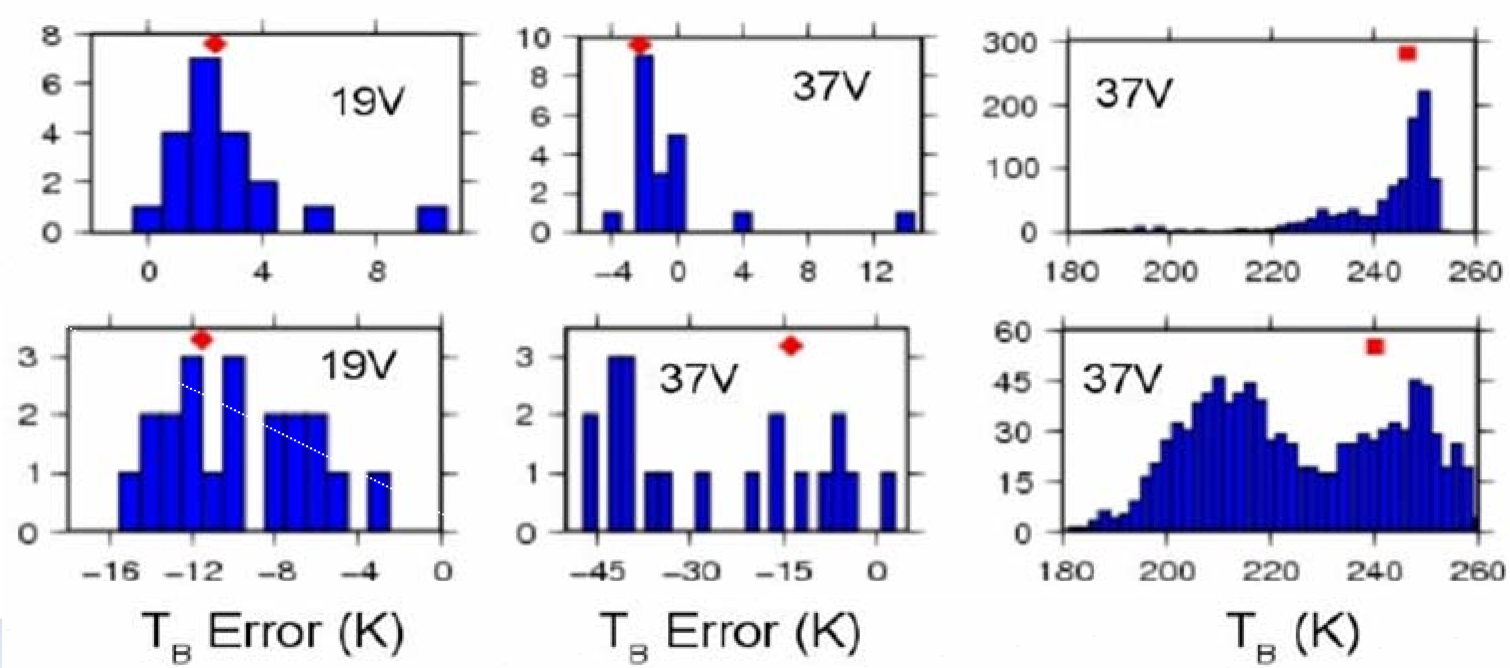
Vertical

Spatial scaling of T_B prediction errors

- Coarse scale of satellite observations
- Data assimilation can act as downscaling technique
- Need to understand how T_B predictions at the model scale relates to the measurement scale

Spatial histograms of TB model prediction errors at 6 km resolution (blue) and 25 km (red point)

Aircraft measurements (resampled at 1 km, blue) and AMSR-E observation (red point)



Fraser (dense forest)

North Park (partial snow coverage)

Future research

- Expand the validation of EM models at different sites
- Include multi-layer models in the framework
  - DMRT, MEMLS
  - VIC multi-layer snow model, enhanced NOAH
- Incorporate DMRT, LSMEM, MEMLS into the CRTM code framework (augmenting the current emissivity parameterization)
- Evaluate TOA TB from NOAH/CRTM with AMSR-E over scales similar to the operational WRF model

Thank You!

- Andreadis et al. 2007: Characterization of errors in a coupled snow hydrology-microwave emission model, *J. Hydrometeorology (in review)*
- *Woijcik et al. 2007: Multi-model estimation of microwave emission during CLPX '03 using operational parameterization of micro-physical snow characteristics, J. Hydrometeorology (in review)*