Predictions of the brightness temperature using the coupled land surface-radiative transfer models

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INTRODUCTION

- Snow cover modulates energy and water fluxes at the surface due to its thermal and hydrologic characteristics (e.g., high albedo and low thermal conductivity).
- As the snowpack is one of the most important freshwater reservoirs, understanding its spatial and temporal variations is crucial for hydrologic and climate studies.
- It has been demonstrated that radiance assimilation (RA), which assimilates passive microwave (PM) brightness temperature (Tb) observations directly into the land surface model (LSM), can be used to improve snow water equivalent (SWE) estimates compared to the assimilation of Tb-based SWE retrievals (e.g., Durand et al. 2009; Toure et al. 2011).
- In RA, a radiative transfer model (RTM) is used as an observational operator to predict Tb observations.
- This study is a preliminary study that aims to assess the performance of the coupled LSM/RTM in predicting Tb for non-vegetated and vegetated areas.

STUDY AREA & DATA

<Rabbit Ears MSA>

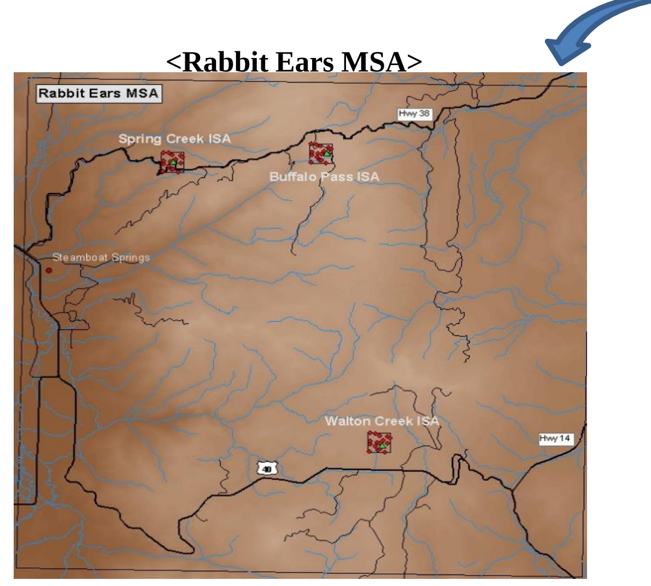


Fig. 2. Rabbit Ears Meso-cell Study Area (MSA) snowpit map (from http://nsidc.org/data/clpx/clpx_pits.html#northpark)

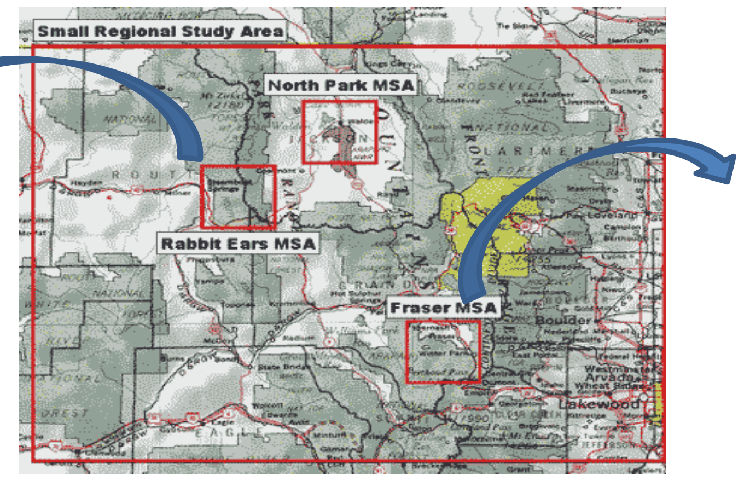


Fig. 1. The Small Regional Study Area (SRSA) and three Meso-cell Study Areas (MSAs) for the Cold Land Processes Field Experiment (CLPX) (from http://www.nohrsc.nws.gov/~cline/clp/field_exp/clpx_plan/figures/CLPX_plan_fig3.htm)

<Fraser MSA>

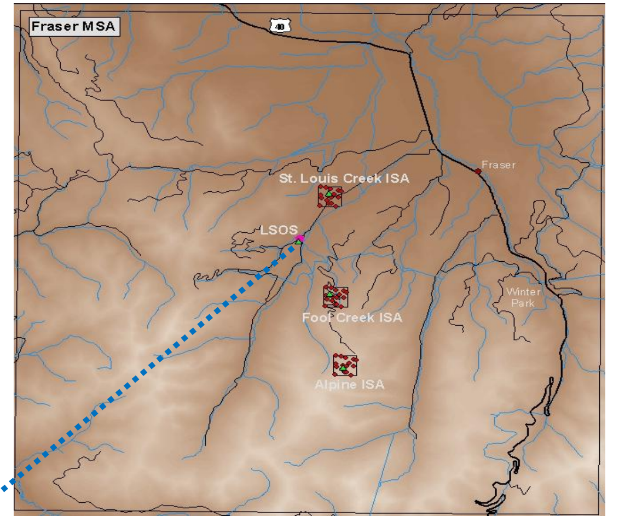


Fig. 3. Fraser Meso-cell Study Area (MSA) snowpit map (from http://nsidc.org/data/clpx/clpx_pits.html#northpark)

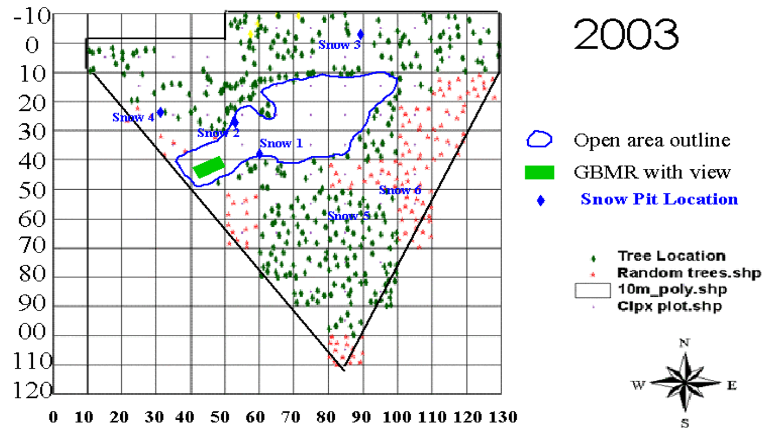
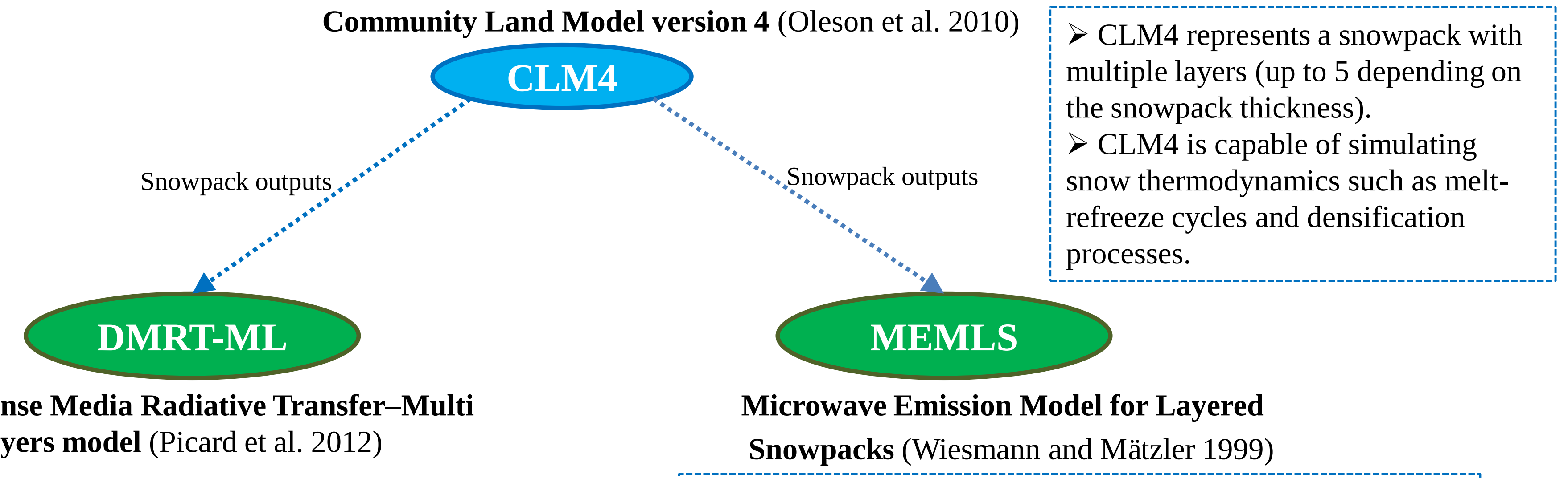


Fig. 4. The snowpit location within the Local Scale Observation Site (LSOS) in 2003 (from http://nsidc.org/data/docs/daac/nsidc0169_clpx_lsos_snow/#spatialcover)

- For the non-vegetated case: LSOS in-situ snowpit and Ground-Based Passive Microwave Radiometer (GBMR-7) data
- For the vegetated case: Intensive Study Area (ISA) in-situ snowpit (for Rabbit Ears MSA), LSOS in-situ snowpit (for Fraser MSA) and airborne Polarimetric Scanning Radiometer (PSR/A) data

MODELS



Community Land Model version 4 (Oleson et al. 2010)

CLM4

Snowpack outputs

Snowpack outputs

DMRT-ML

Dense Media Radiative Transfer–Multi Layers model (Picard et al. 2012)

MEMLS

Microwave Emission Model for Layered Snowpacks (Wiesmann and Mätzler 1999)

- CLM4 represents a snowpack with multiple layers (up to 5 depending on the snowpack thickness).
- CLM4 is capable of simulating snow thermodynamics such as melt-refreeze cycles and densification processes.

- Theoretical (physical) model
- Required inputs: 1) Snow layer temperature (K)
  2) Wetness (fraction)
  3) Snow density (kg m^{-3})
  4) Snow layer thickness (m)
  5) Effective grain radius (㎛)

- Semi-empirical model
- Required inputs: 1) Snow layer temperature (K)
  2) Wetness (fraction)
  3) Snow density (kg m^{-3})
  4) Snow layer thickness (cm)
  5) Exponential correlation length (mm)

BRIGHTNESS TEMPERATURE FOR NON-VEGETATED AREA

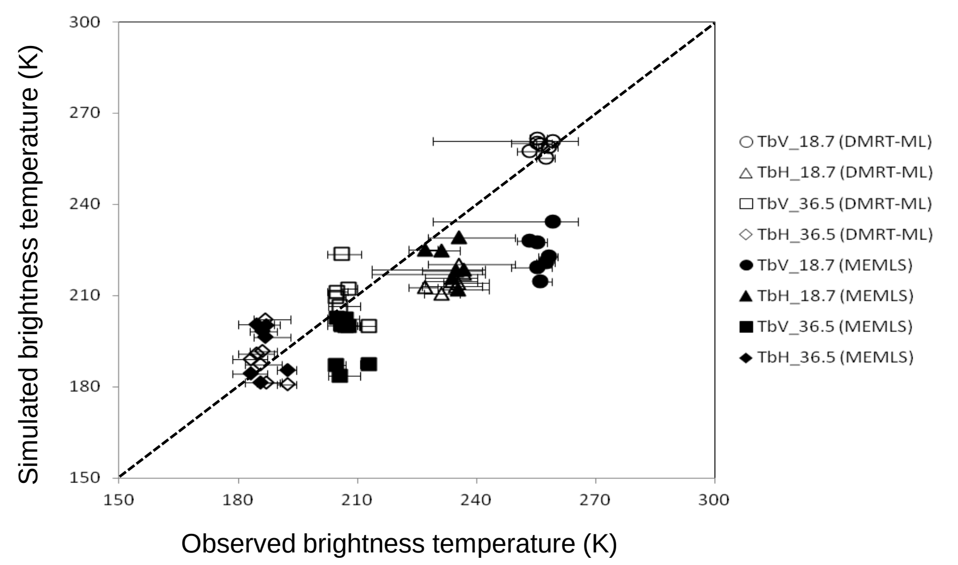


Fig. 5. Observed versus simulated brightness temperature by MEMLS and DMRT-ML using snowpit measurements collected within the LSOS

Table 1. The errors of brightness temperatures simulated by MEMLS and DMRT-ML using snowpit measurements collected within the LSOS.

	DMRT-ML				MEMLS			
	18.7 GHz		36.5 GHz		18.7 GHz		36.5 GHz	
	TbV	TbH	TbV	TbH	TbV	TbH	TbV	TbH
RMSE (K)	3.69	19.22	9.30	8.55	33.20	15.11	14.90	10.20
MBE (K)	2.55	-19.03	1.92	2.32	-32.60	-13.19	-12.34	5.73

- Though DMRT-ML slightly overestimated Tb, except for 18.7 GHz horizontal polarization channel, it shows relatively good agreement with the observations compared to those by MEMLS.
- Tb simulated by MEMLS shows somewhat larger errors, in particular, for 18.7 GHz vertical polarization channel. In contrast to DMRT-ML, MEMLS underestimated Tb, except for 36.5 GHz horizontal polarization channel.
- However, it should be noted that any parameter in MEMLS was not calibrated while the stickiness parameter (= 0.17) in DMRT-ML was calibrated.
- Therefore, it cannot be stated that the performance of DMRT-ML in estimating Tb of the snowpack is better than MEMLS.

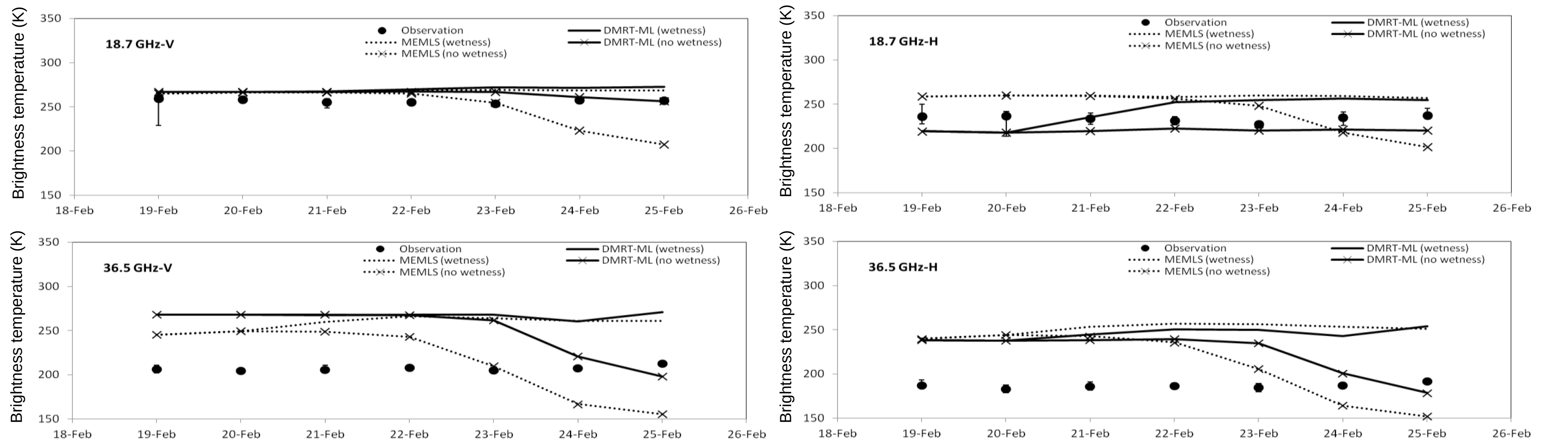


Fig. 6. Observed and simulated brightness temperature by the coupled CLM4/DMRT-ML and CLM4/MEMLS for the LSOS

Table 2. The errors of brightness temperatures simulated by the coupled CLM4/DMRT-ML and CLM4/MEMLS for the LSOS

	DMRT-ML				MEMLS			
	18.7 GHz		36.5 GHz		18.7 GHz		36.5 GHz	
	TbV	TbH	TbV	TbH	TbV	TbH	TbV	TbH
RMSE (K)	13.40	19.06	60.29	59.24	11.39	25.24	51.54	64.54
MBE (K)	12.93	7.58	60.20	59.04	10.99	24.95	51.09	64.24

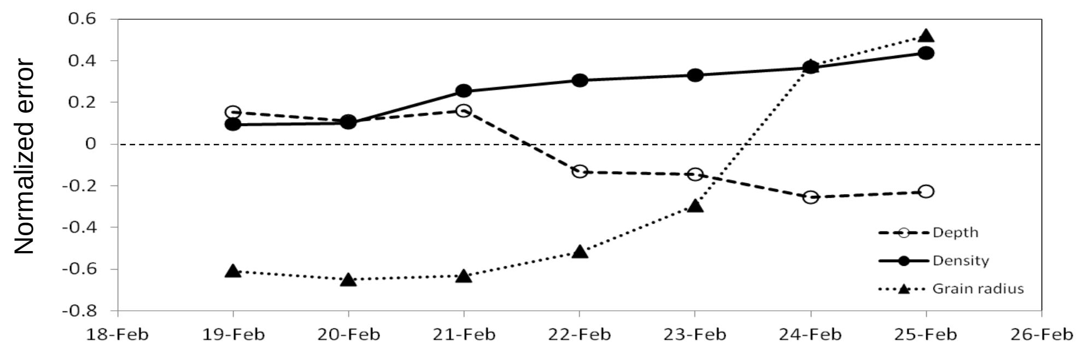


Fig. 7. Normalized errors (=(simulation – observation)/observation) for snow depth, density and grain radius

- In-situ snowpit measurements show dry snowpack conditions without wetness, but the model simulates that the snowpack starts to have liquid water since 21 February.
- When liquid water exists within the snowpack, scattering effect of the snowpack is reduced and the emission by liquid water becomes the primary Tb source.
- Therefore, after 21 February, Tb shows the different trend between the results with and without considering simulated wetness and the abrupt decline on 24 and 25 February when the wetness is not considered.
- However, DMRT-ML and MEMLS show different sensitivity to the wetness.
- Changes in Tb due to the wetness are greater in MEMLS.

- Different from the results using in-situ snowpit measurements, both models overestimated Tb and show the similar degree of error when simulated wetness is considered.
- Snow density and depth were overestimated and grain radius was underestimated before 21 February.
- Shallower snow depth, larger density and smaller grain size lead to higher Tb.
- Due to the greater sensitivity of Tb to snow grain size and density compared to the depth, both DMRT-ML (except for 18.7 GHz-H) and MEMLS overestimated Tb before 21 February.
- One thing to note is that the grain size error decreases after 21 February and the model overestimates it after 24 February while the simulated Tb does not show the corresponding change.
- Since snow grain radius is mainly involved in scattering process and larger grain size leads to the increased scattering, Tb should be underestimated based on the normalized error.

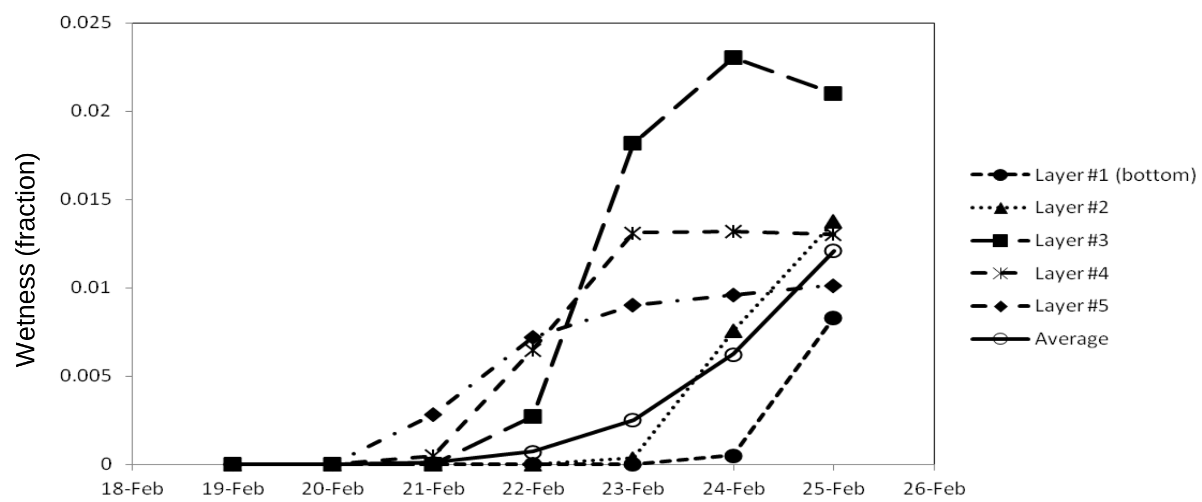


Fig. 8. Simulated wetness by CLM4 during 19-25 February 2003 over the LSOS

BRIGHTNESS TEMPERATURE FOR VEGETATED AREA

- To predict airborne Tb (PSR/A), the effects of the atmosphere (Ulaby et al. 1981) and vegetation canopy (Jackson and Schmugge 1991) were considered.
- Using in-situ snowpit and PSR/A data sets, the empirical coefficient *b'* and *x* in Equation (1) (Jackson and Schmugge 1991) were calibrated.

$$\tau_c = b'\lambda^x w_c / \cos\theta \qquad (1)$$

τ_c : vegetation optical depth
λ : wavelength (cm)
θ : incident angle
b' and x : empirical coefficients
w_c : vegetation water content (kg m^{-2})

Table 3. The calibrated values of the empirical coefficients for the Fraser and Rabbit Ears MSAs

	Fraser MSA	Rabbit Ears MSA
b'	0.62	0.62
x	-0.6	-0.5

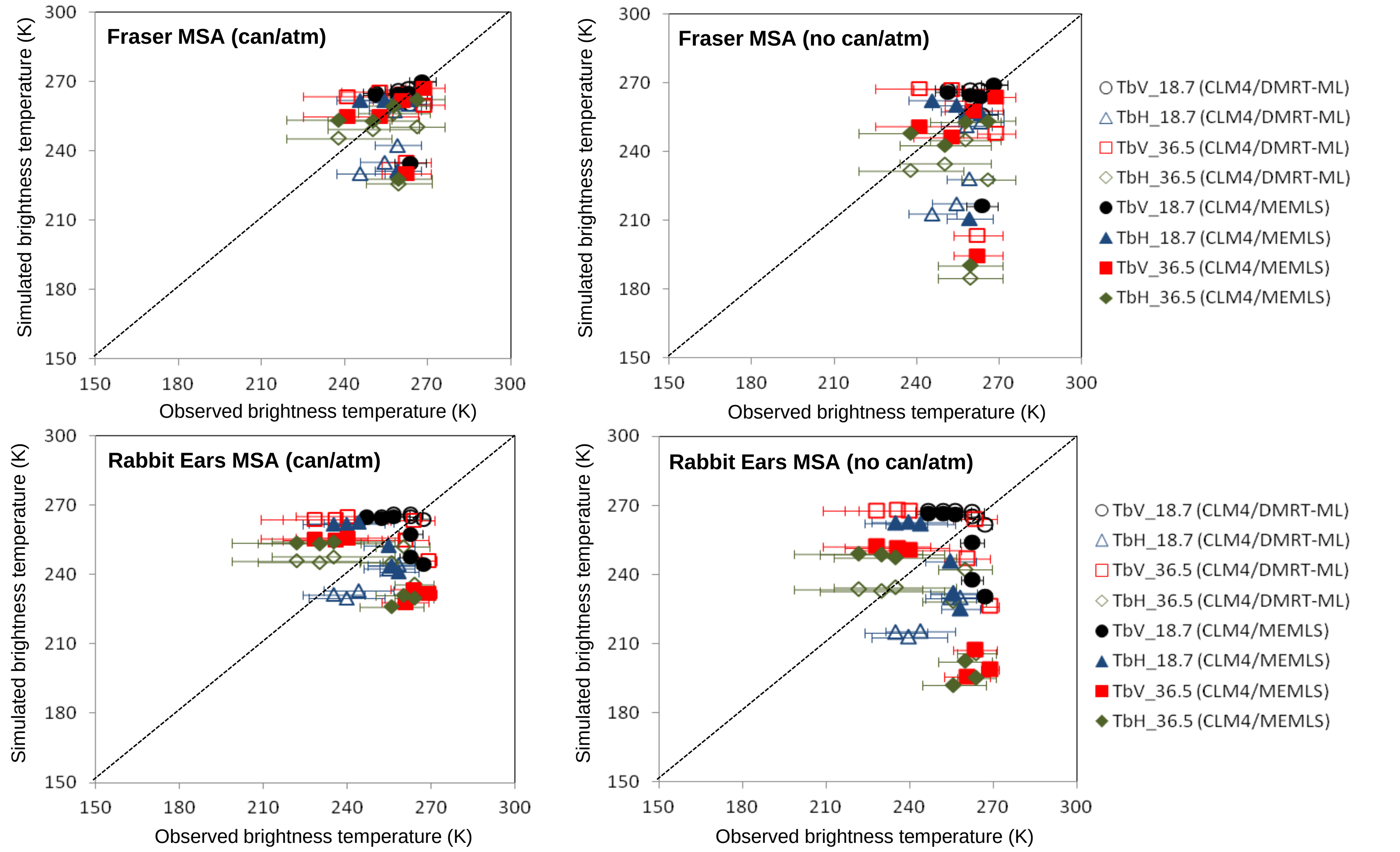


Fig. 9. Observed versus simulated brightness temperature by the coupled CLM4/DMRT-ML and CLM4/MEMLS for the Fraser and Rabbit Ears MSAs

Table 4. The errors of brightness temperatures simulated by the coupled CLM4/DMRT-ML and CLM4/MEMLS (with considering the effects of the atmosphere and vegetation canopy) for the Fraser and Rabbit Ears MSAs

can/atm		DMRT-ML				MEMLS			
		18.7 GHz		36.5 GHz		18.7 GHz		36.5 GHz	
		TbV	TbH	TbV	TbH	TbV	TbH	TbV	TbH
Fraser MSA	RMSE (K)	7.26	13.55	17.37	17.04	14.35	14.79	15.73	15.93
	MBE (K)	4.52	-11.15	0.49	-8.93	-1.46	-0.56	-3.44	-3.18
Rabbit Ears MSA	RMSE (K)	10.33	10.86	23.34	18.04	14.69	18.22	28.00	28.37
	MBE (K)	7.49	-10.37	10.20	1.05	-0.55	6.14	-6.06	-2.92

Table 5. The errors of brightness temperatures simulated by the coupled CLM4/DMRT-ML and CLM4/MEMLS (without considering the effects of the atmosphere and vegetation canopy) for the Fraser and Rabbit Ears MSAs

no can/atm		DMRT-ML				MEMLS			
		18.7 GHz		36.5 GHz		18.7 GHz		36.5 GHz	
		TbV	TbH	TbV	TbH	TbV	TbH	TbV	TbH
Fraser MSA	RMSE (K)	8.71	26.84	31.02	38.80	22.34	23.27	30.77	32.07
	MBE (K)	4.09	-23.74	-7.52	-29.58	-5.18	-6.83	-14.48	-16.94
Rabbit Ears MSA	RMSE (K)	11.87	25.75	29.95	27.70	21.29	23.57	46.95	47.25
	MBE (K)	8.18	-25.59	7.34	-14.89	-4.44	0.34	-23.38	-22.02

CONCLUSIONS

- The coupled CLM4/DMRT-ML and CLM4/MEMLS show the similar degree of errors for both non-vegetated and vegetated areas.
- MEMLS has greater sensitivity to the snowpack wetness than DMRT-ML.
- Considering the effects of the atmosphere and vegetation canopy improves the Tb predictions by the coupled LSM/RTM for vegetated area.
- For the vegetated case, the difference in Tb between frequency channels is reduced compared to the non-vegetated case.
- For radiance assimilation, some significant parameters such as the stickiness (for DMRT-ML case) and empirical coefficients (*b'* and *x* for vegetation optical depth) should be carefully determined.

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