Reducing CLM Albedo Biases in Snow-Effected Forests with Improved Canopy Scheme

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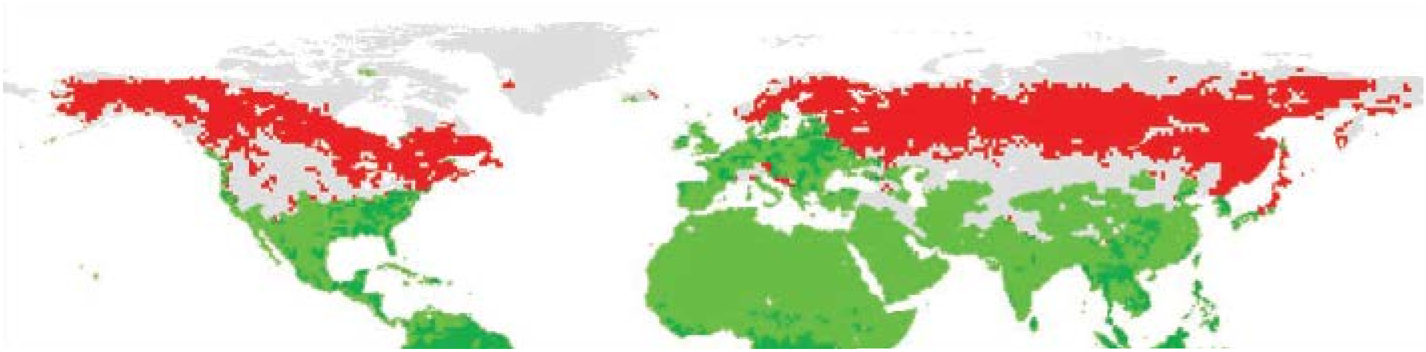
Motivation

- Significant seasonal albedo variance and biases exist over snowy forested regions in current global climate models, impacting the certainty of North Hemisphere land warming predictions[1,2]
- CLM has a higher mid-winter albedo in these regions than satellite measurements, and a larger spring decline than observed[3]



Snow-covered Forest in red, *SNOWMIP2*

1. Qu, X., and A. Hall (2014), *Clim. Dyn.*
2. Essery, R. (2013), *Geophys. Res. Lett.*
3. Thackeray, C. W., C. G. Fletcher, and C. Derksen (2014), *J. Geophys. Res. Atmos.*

Current CLM Canopy Snow Treatment

Causes of albedo differences and surface feedback biases:

- Canopy snow only exists as optics parameterization
- With sharp "switch": when T>273 K, optic values are snow-free

if (t_veg(p) > tfrz) then   ! no snow

$$\omega = \omega_{leaf}$$

$$\beta = \beta_{leaf}$$

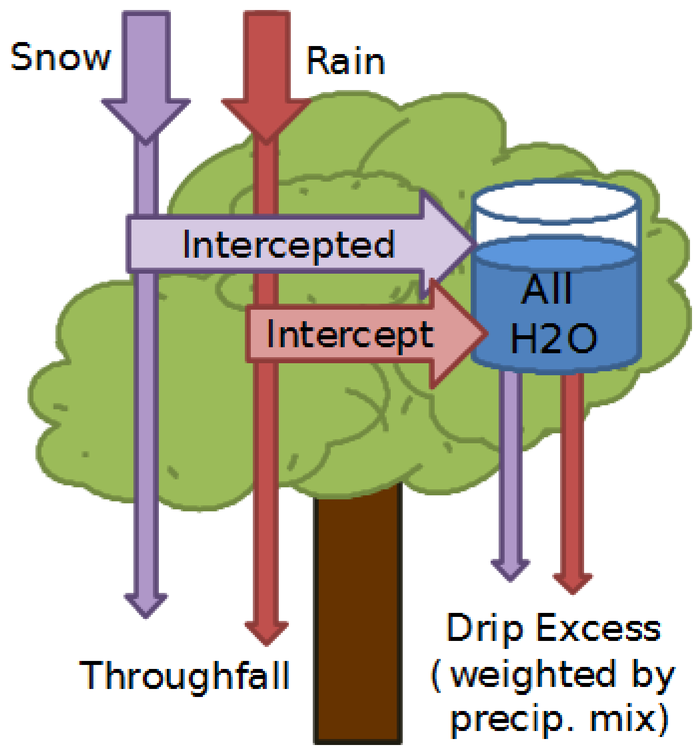
else   ! snow

$$\omega = (1 - f_{wet})\omega_{leaf} + f_{wet}\omega^{snow}_{leaf}$$

$$\beta = (1 - f_{wet})\beta_{leaf} + f_{wet}\beta^{snow}_{leaf}$$

end if

Current Canopy Radiation

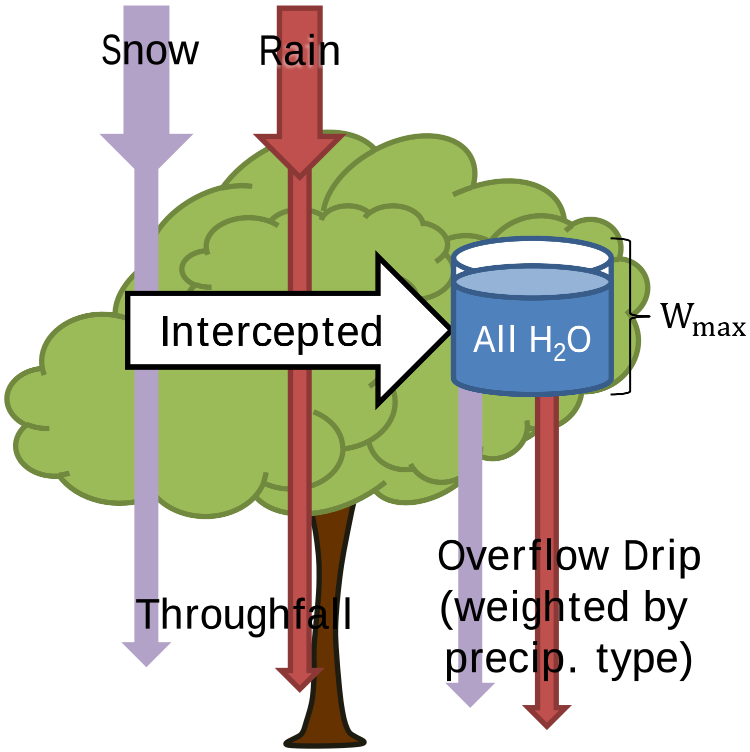


Current Canopy Hydrology

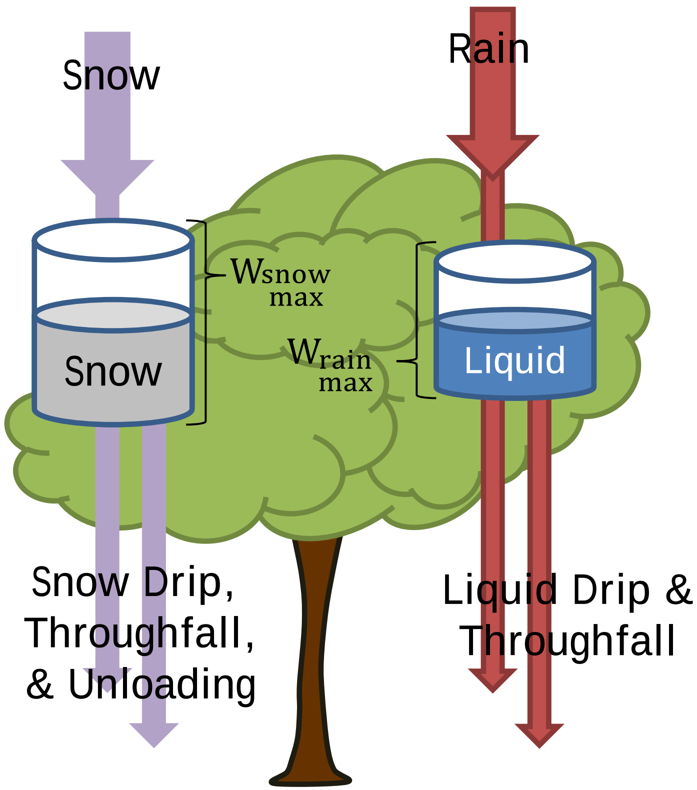
Development CLM Canopy Snow Treatment

- Implemented an enhanced vegetation hydrology treatment in a CLM 4.5 development branch tuned to tower observations, with updates to the canopy two-stream radiation scheme.
- Result is more realistic canopy snow interception compared to site measurements, and reduced model albedo biases compared to satellite

Development CLM Canopy Snow Treatment



Current Canopy Hydrology



New Implementation

Development CLM Canopy Snow Treatment

- Max Storage Capacities (mm)
  - Current:

    $$W_{max} = (0.1\ \text{kg})(\text{LAI+SAI})$$

  - Development:

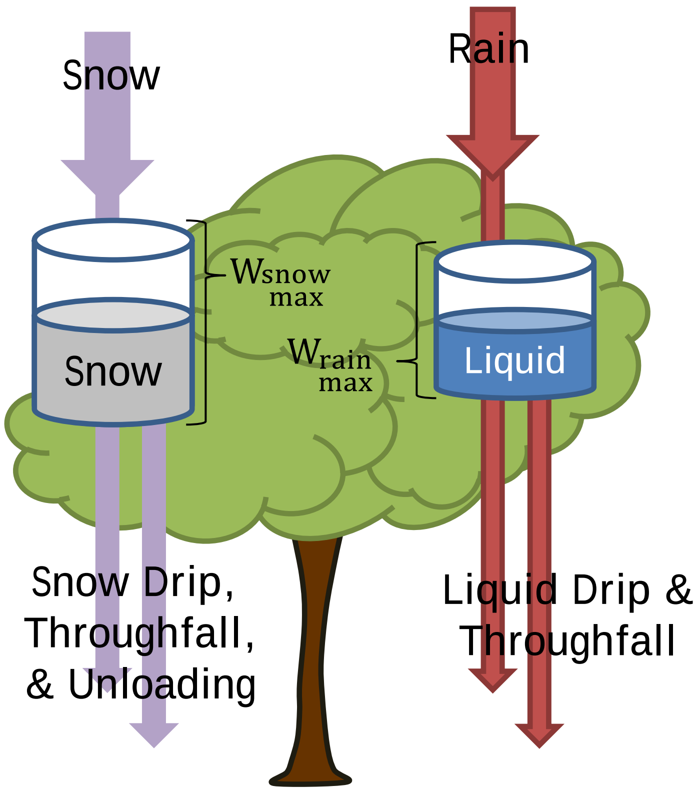
    $$W_{\substack{rain\\max}} = (0.1\ \text{kg})(\text{LAI+SAI})$$

    $$W_{\substack{snow\\max}} = c_1(0.1\ \text{kg})(\text{LAI+SAI})$$

- Drip Variables:

  $Q_{\substack{sno\\drip}}$ = snow exceeding max storage

  $Q_{\substack{liq\\drip}}$ = liquid exceeding max storage



New Implementation

Development CLM Canopy Snow Treatment

- Unloading schemes
  - Based on *Roesch, 2001*
  - Rapid unloading caused by melt/slipping *(Nakai et al, 1994) and* wind *(Yamazaki et al. 1996)*
  - $Q_{\substack{temp\\unload}} = \frac{T-270K}{c_2}$, $Q_{\substack{wind\\unload}} = \frac{\sqrt{u^2+v^2}}{c_3}$

- Leaf vapor fluxes unchanged, taken from snow or liquid

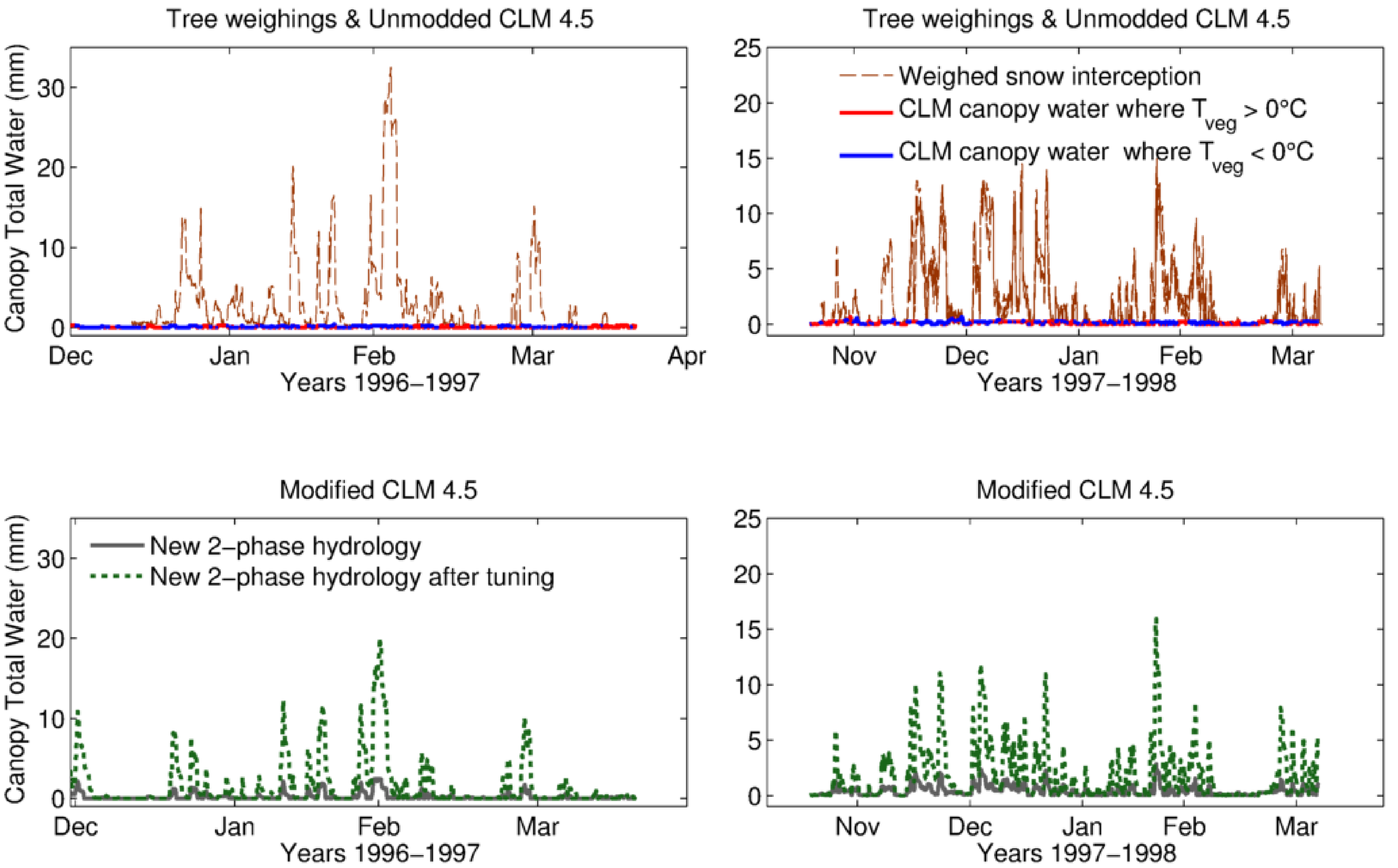
- Precip to Ground:
  - Current: $Q_{\substack{grnd\\snow}} = Q_{\substack{through\\snow}} + f_{snow}Q_{drip}$
  - New: $Q_{\substack{grnd\\snow}} = Q_{\substack{through\\snow}} + f_{snow}Q_{drip} + Q_{\substack{temp\\unload}} + Q_{\substack{wind\\unload}}$

Interception Measurements

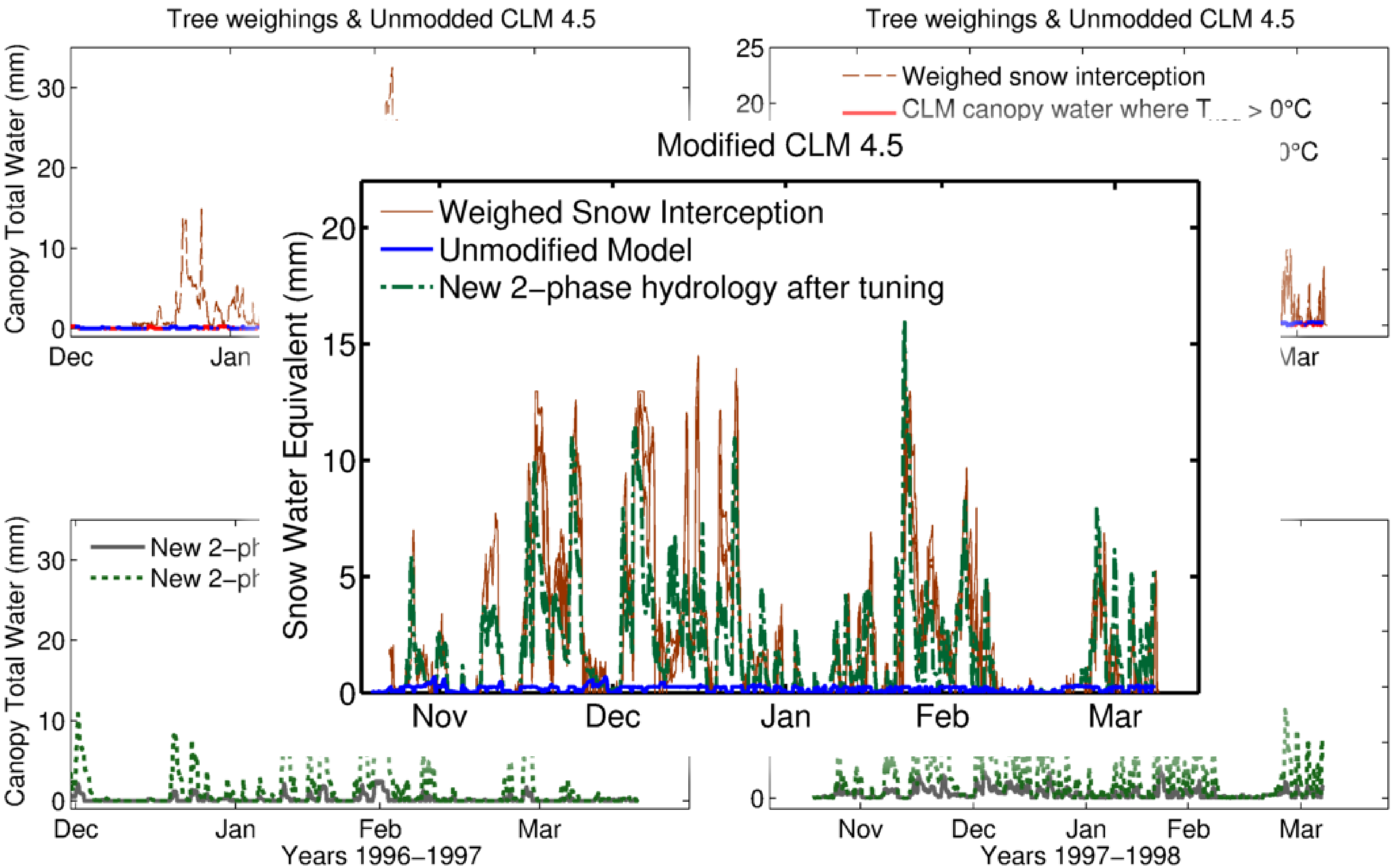
- Single-point CLM 4.5 compared with evergreen canopy snow measurements collected in the Umpqua Forest, OR. Atmospheric conditions taken concurrently with weighings used as model forcing
- Validity of unloading strength were confirmed. Snow interception efficiency and maximum snow storage capacity were tuned to observations

Storck, Lettenmaier, and Bolton (2002)

Interception Measurements



Interception Measurements



Removing Optics' Temp. Dependence

Existing Canopy Snow Optics:

$$\omega = \begin{cases} \omega_{leaf}, & T_{veg} > 0°C \\ (1 - f_{wet})\omega_{leaf} + f_{wet}\omega_{\substack{snow,\\ leaf}} & T_{veg} < 0°C \end{cases}$$

$$\beta = \begin{cases} \beta_{leaf}, & T_{veg} > 0°C \\ (1 - f_{wet})\beta_{leaf} + f_{wet}\beta_{\substack{snow\\ leaf}}, & T_{veg} < 0°C \end{cases}$$

$$f_{wet} = \left(\frac{H_2O}{\max H_2O}\right)^{\frac{2}{3}}$$

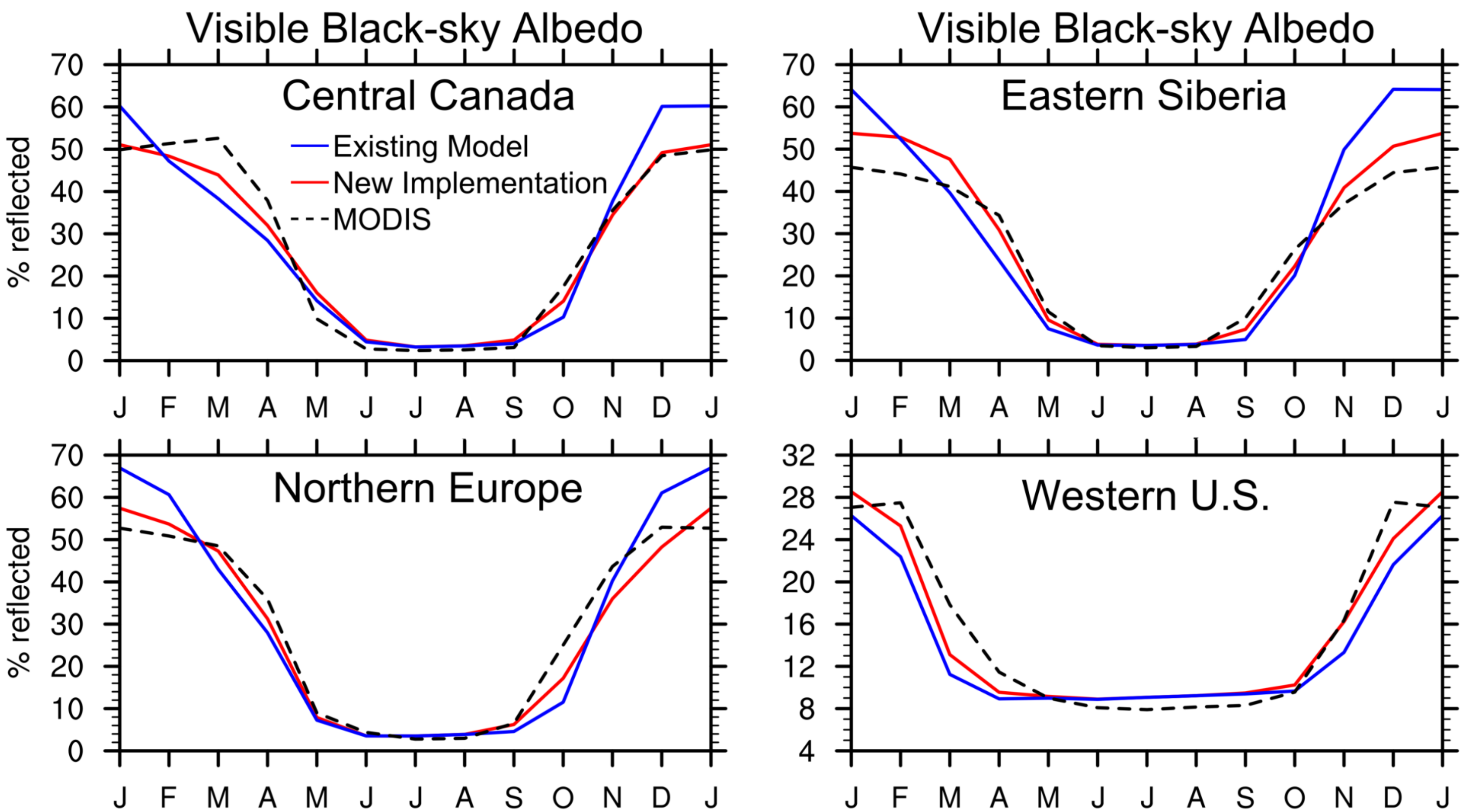
$$f_{cansnow} = \left(\frac{\text{canopy snow}}{\max \text{snow}}\right)^{c}$$

New Implementation:

$$\omega = (1 - f_{cansnow})\omega_{leaf} + f_{cansnow}\omega_{\substack{snow\\ leaf}}$$

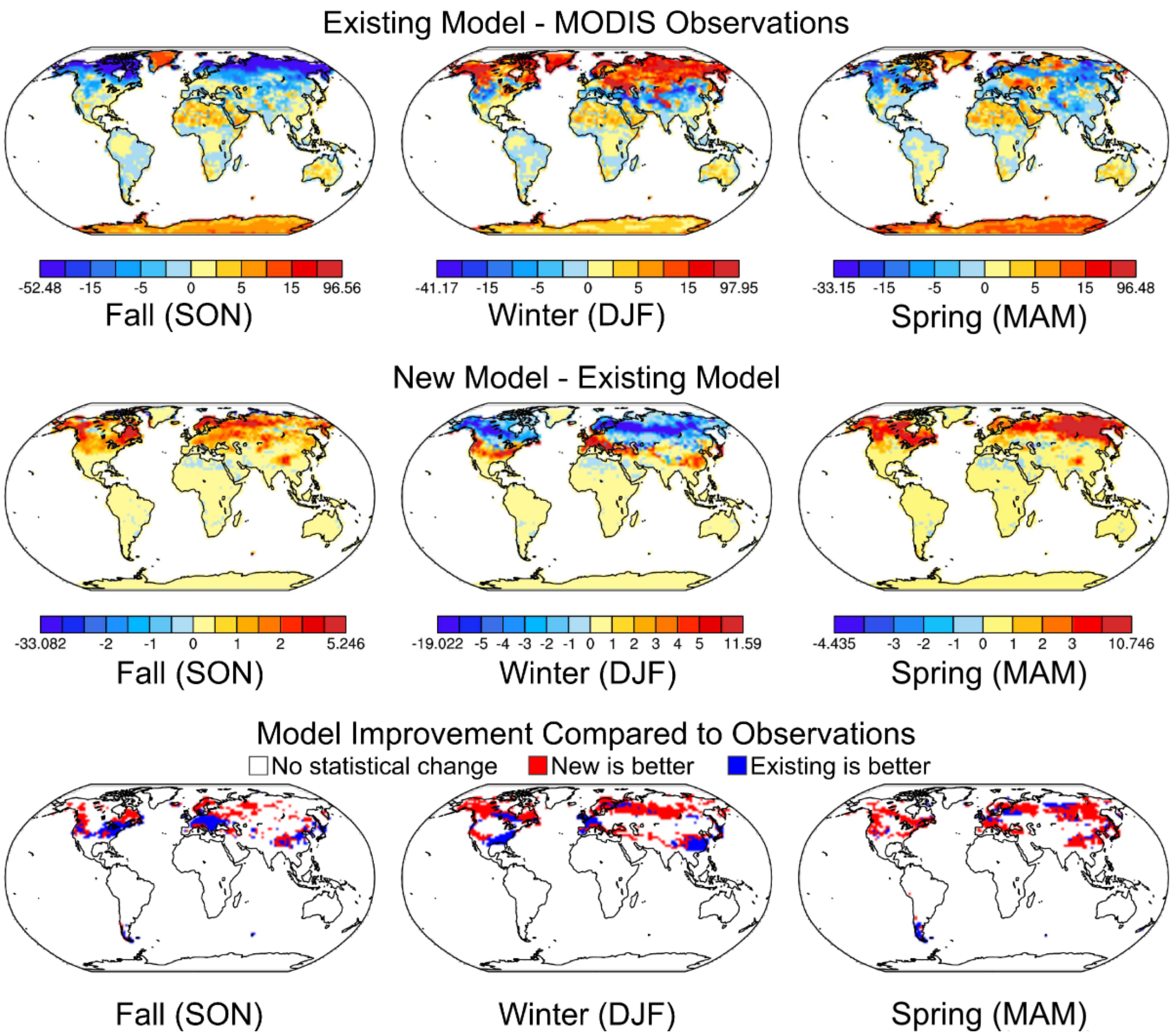
$$\beta = (1 - f_{cansnow})\beta_{leaf} + f_{cansnow}\beta_{\substack{snow\\ leaf}}$$

Model Evaluation - Regional

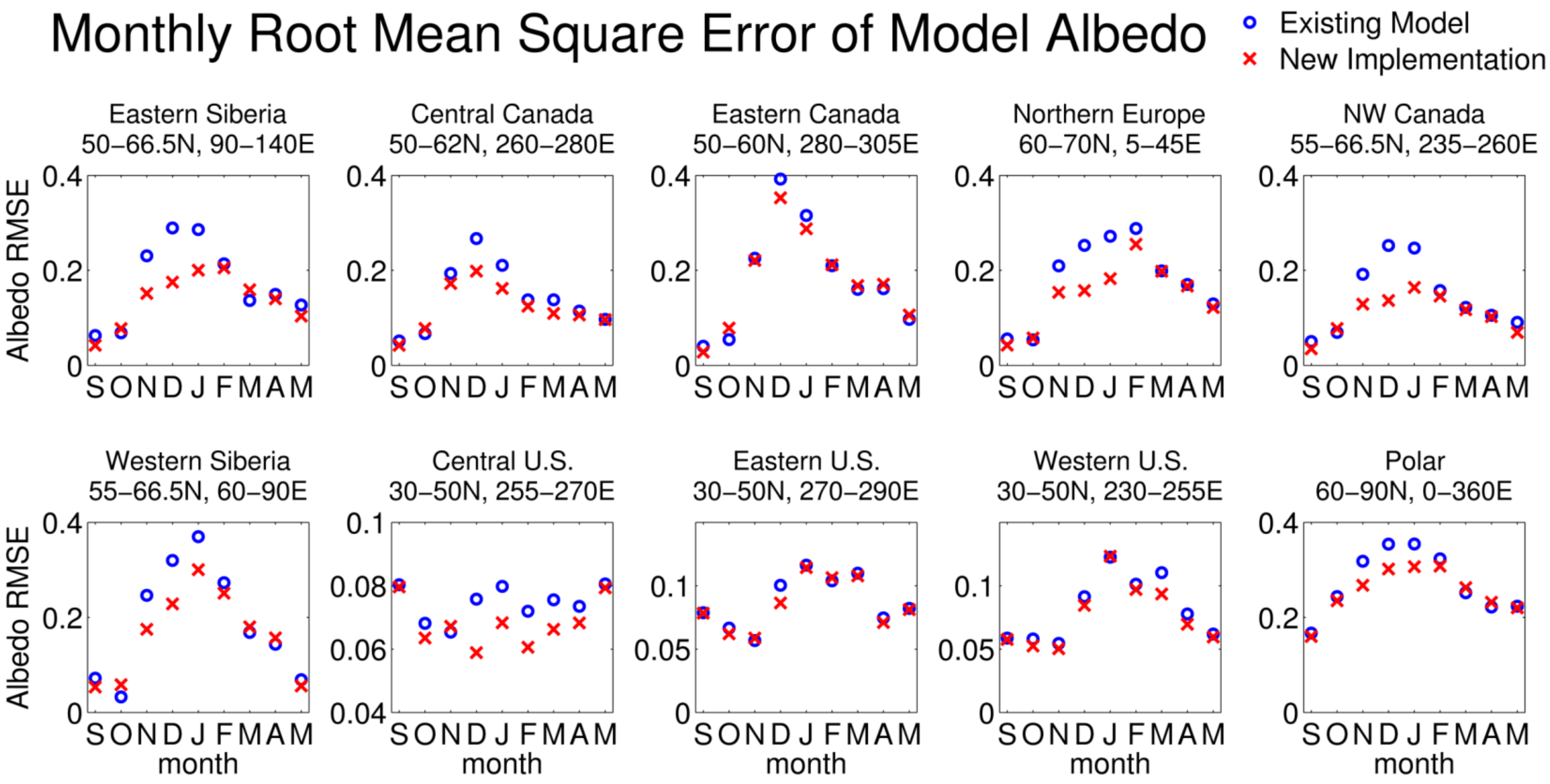


Model Evaluation - Global

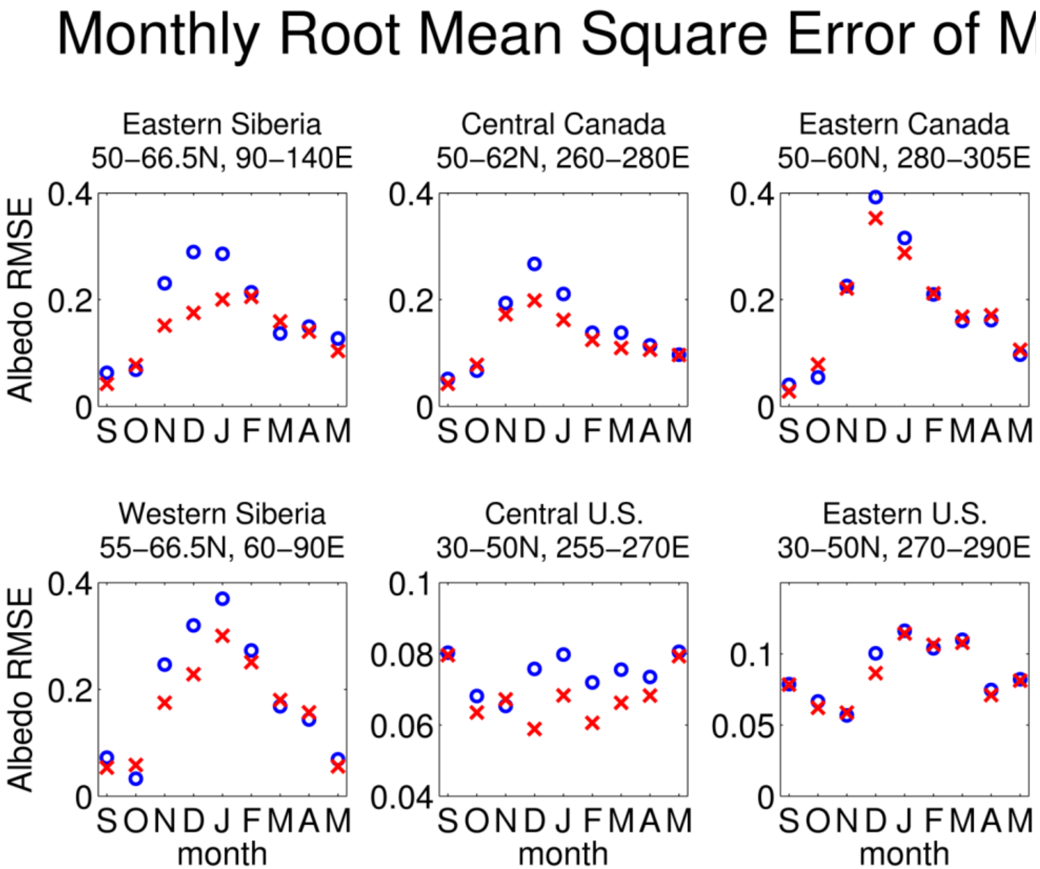
Seasonal Visible Black-sky Albedo Compared with MODIS



Model Evaluation - Regional



Model Evaluation - Regional



Annual Average Error Reduction by Region	
East Siberia	-12 %
Western Siberia	-3.0 %
Central Canada	-9.5 %
Eastern Canada	-0.7 %
Northern Europe	-11 %
NW Canada	-15 %
Central US	-6.5 %
Eastern US	-2.1 %
Western US	-5.0 %
Polar	-4.2 %

Model Evaluation – Skill Score

- Skill score evaluates model albedo and ground snowcover fraction biases with multiple obs. datasets (Thackeray, Fletcher, Derkeson, *submitted*)

Boreal Evergreen Needleleaf Skill Score			
Model	SS_{alb}	SS_{scf}	SS_{tot}
CCSM4	0.763	0.891	0.827
CLM4 (Qian)	0.719	0.921	0.82
CLM4.5 (Qian)	0.719	0.938	0.829
CLM4.5 (CRUNCEP)	0.728	0.934	0.831
CLM4.5-snowvegdev (Qian)	**0.868**	**0.934**	**0.901**

Model Evaluation – Skill Score

- Skill score evaluates model albedo and ground snowcover fraction biases with multiple obs. datasets (Thackeray, Fletcher, Derkeson, *submitted*)

Snow-affected North Hemisphere Skill Score			
Model	SS_{alb}	SS_{scf}	SS_{tot}
CCSM4	0.836	0.931	0.884
CLM4 (Qian)	0.743	0.926	0.834
CLM4.5 (Qian)	0.732	0.932	0.832
CLM4.5 (CRUNCEP)	0.766	0.937	0.851
CLM4.5-snowvegdev (Qian)	**0.797**	**0.923**	**0.860**

Summary

- Snowvegdev development branch, slated for CLM 5
- Introducing vegetation canopy snow storage as an explicit variable
- Allows for more realistic vegetation hydrology processes, and canopy albedo treatment, tunable to observations
- Result is the reduction of albedo biases in model snowy boreal regions, and better timing of spring reduction from snowmelt