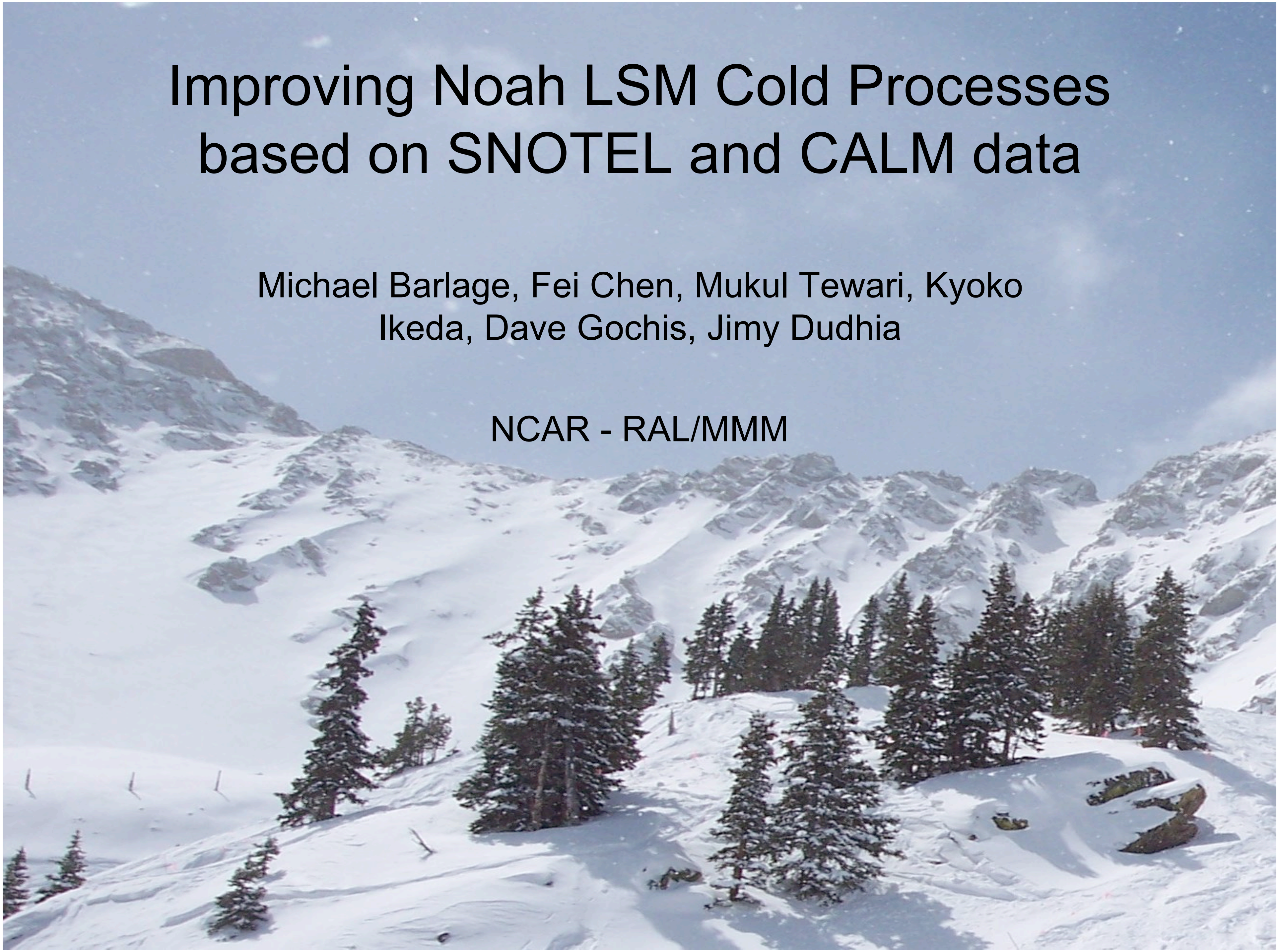
Improving Noah LSM Cold Processes based on SNOTEL and CALM data



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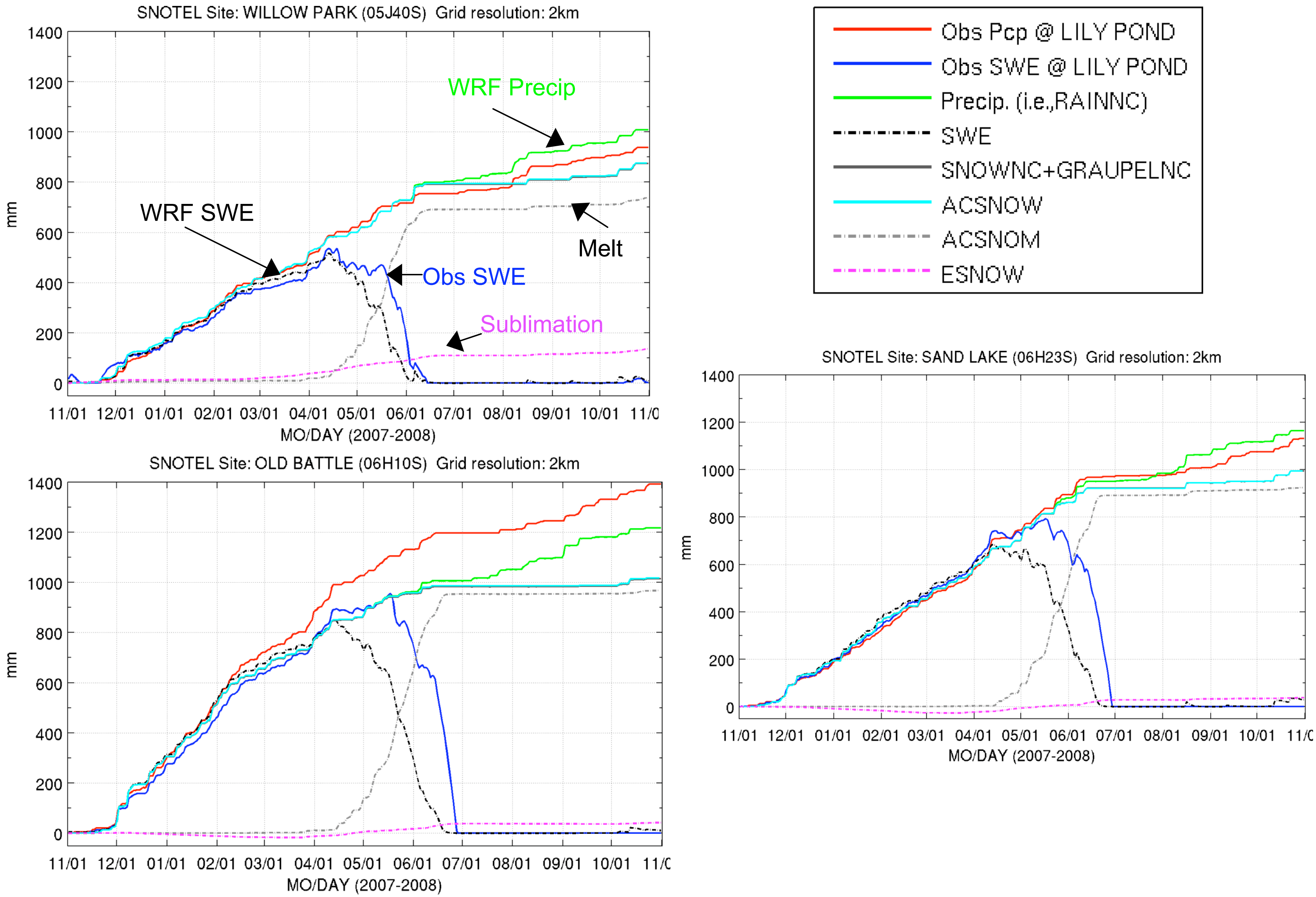
NCAR - RAL/MMM

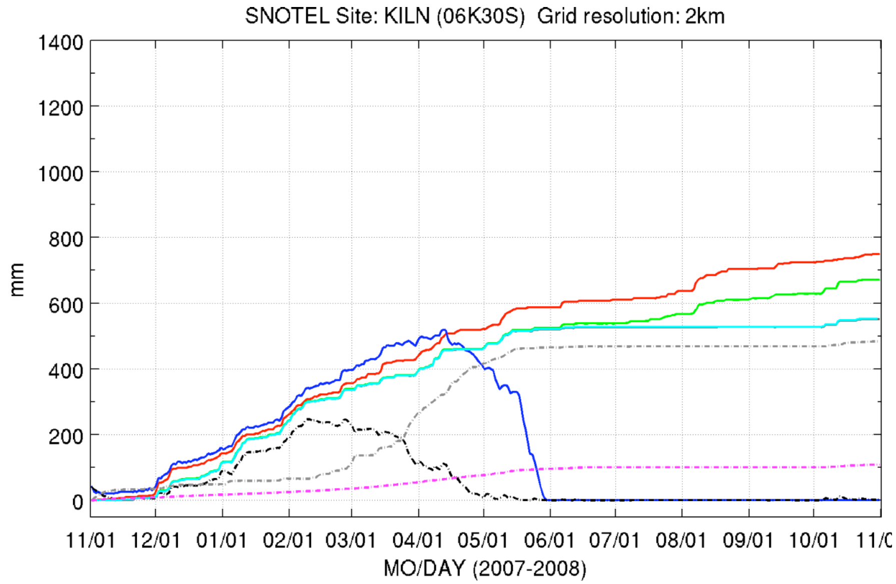
Snow modeling in Noah

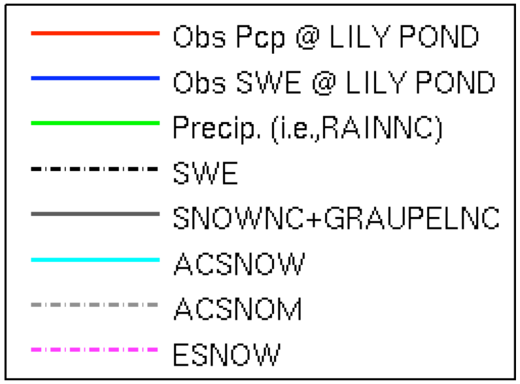
- Snow physics:
  – Currently one-layer snow model in Noah (based on Koren et al. 1999, JGR)
    - Snow density change due to compaction, fractional snow cover, frozen-ground physics
  – Three-layer model development by Guo-Yue Niu and Zong-Liang Yang at UT-Austin
    - This has been coupled to Noah but needs more testing
  – Improving performance of one-layer snow model (work reported here)

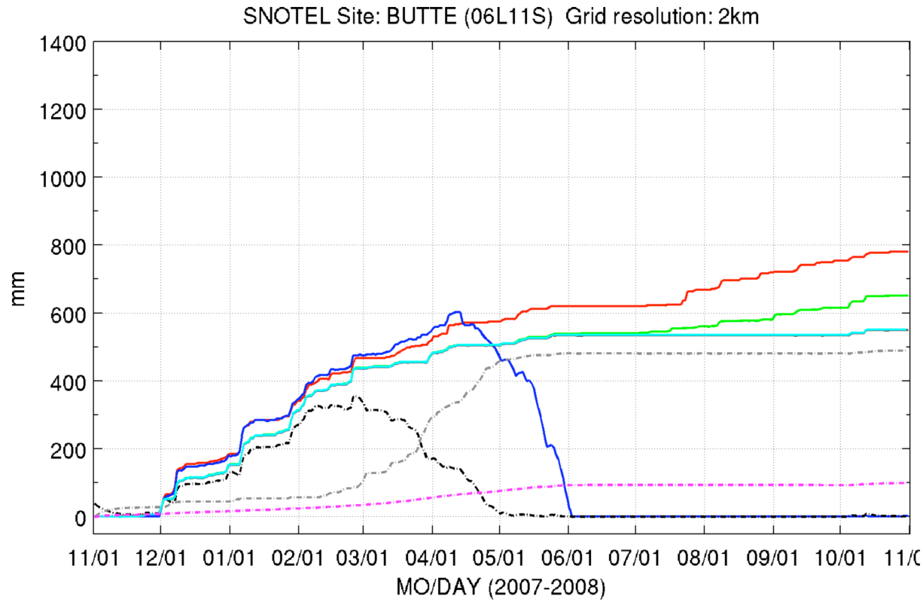
“Good” Sites: Coupled WRF Results

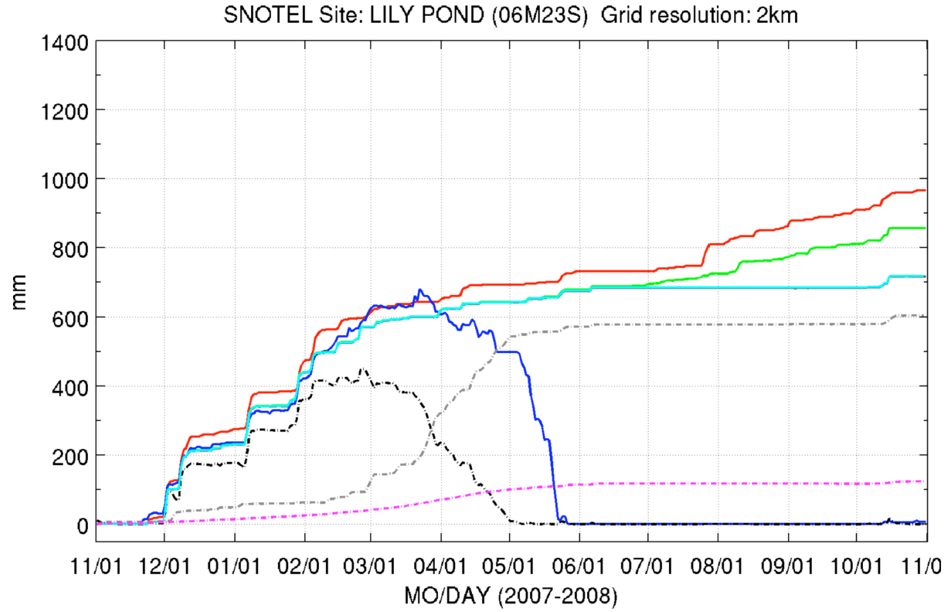


“Bad” Sites: Coupled WRF Results







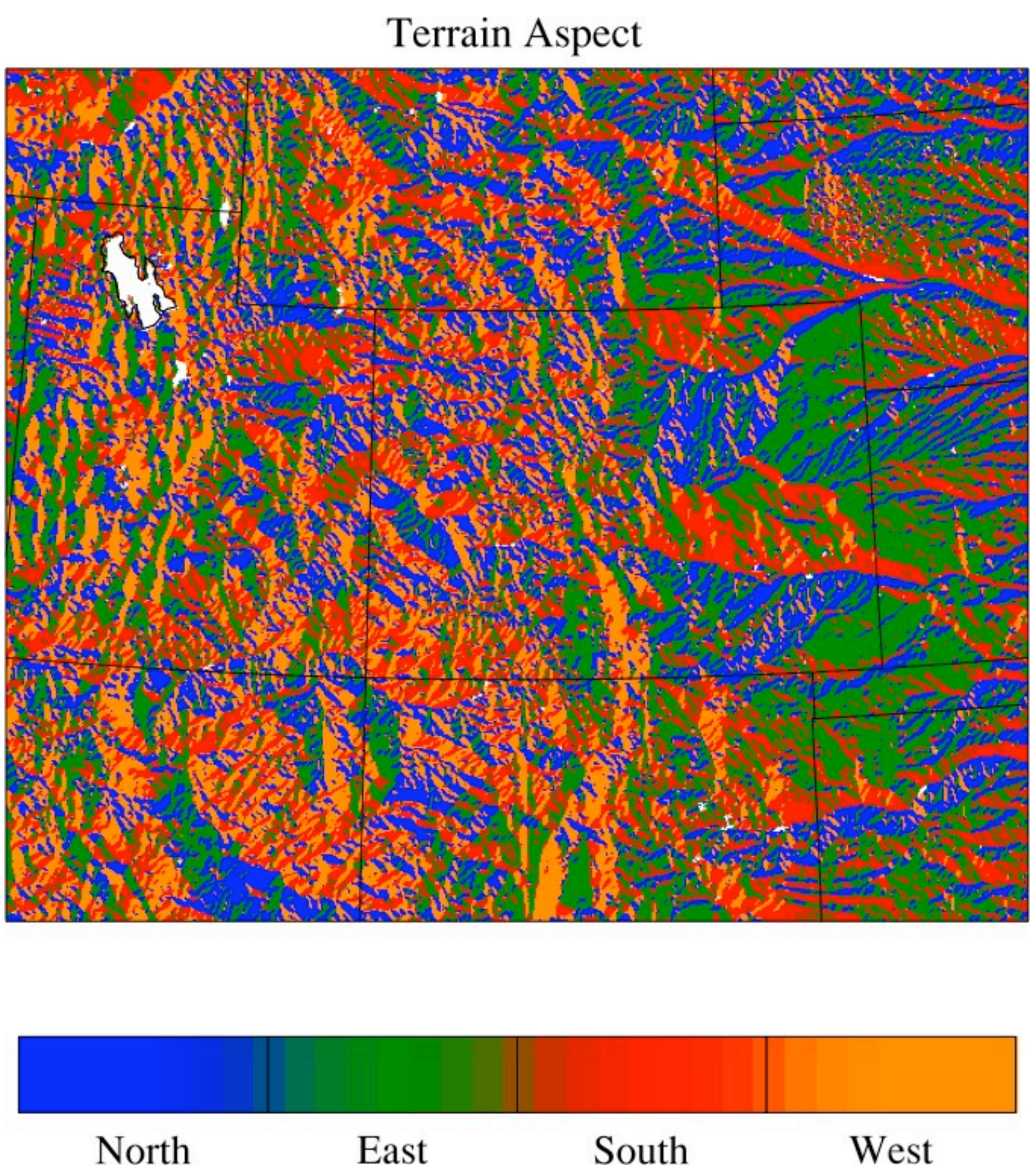


HRLDAS simulations to test new snow options

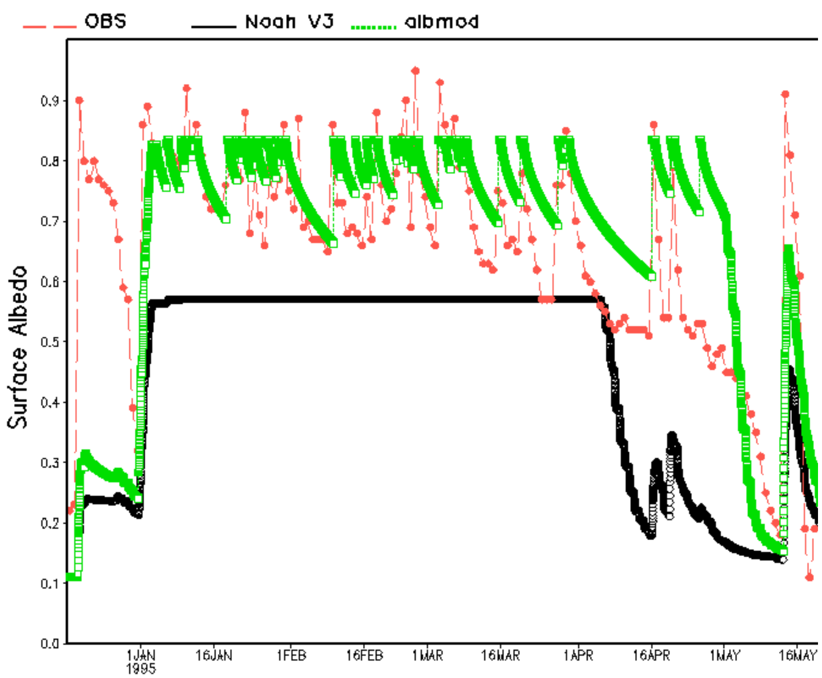
- 12 month simulations (Nov 2007 - Nov 2008) are done using the High Resolution Land Data Assimilation System (HRLDAS)
- Use a 2-km grid centered on the Rocky Mountains
- All forcing variables come from WRF output except for solar radiation
- Use model level forcing to reproduce coupled WRF control simulation
- For solar forcing, use GOES radiation
- Test:
    1. Adjustment for slope and aspect (Zaengl)
    2. Time decaying albedo adjustment (Livneh)
    3. Decoupling surface during stable boundary layers
    4. Increasing maximum snow albedo to 0.85 and adjusting z_0 when snow is present

Included Slope-Aspect Adjustment to Solar Radiation

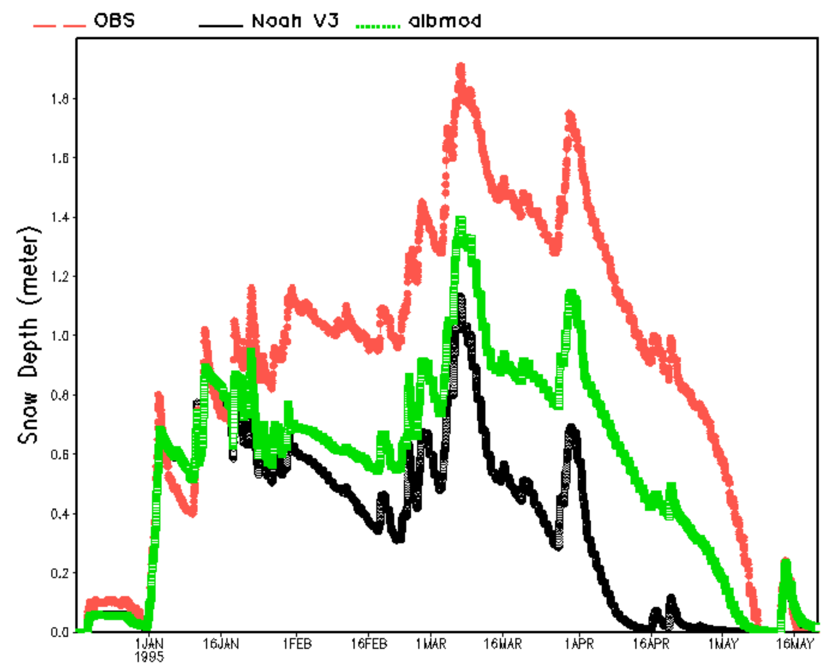
- Grid slope and aspect are calculated from 2km terrain field
- Solar radiation is adjusted based on location of sun and fraction of diffuse radiation
- Shown are the grid aspects binned to the cardinal directions
- Northward facing slopes will receive less radiation, south more, and east/west will affect diurnal cycle of incoming solar



Snow albedo comparison against 94-95 Col de Port (France) data using Livneh's albedo formulation



Albedo



Snow Depth

Red: Obs, Black: V3, Green: V3 with albedo modification

- Snow albedo decreases with time simulating aging effects
- This new formulation is in WRF 3.1

Comparison of Last Date of 5mm SWE

Terrain Height [m]

Simulation options

	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000-3500	3500-4500
Control	34	32	35	75	115	144	167
+Livneh albedo	-1	0	0	0	+3	+4	+4
+terrain	0	0	0	0	0	0	0
+Ch	0	+2	+7	+4	+2	0	0
+Max + z_0	+1	+4	+5	+8	+12	+17	+18
Total	34	38	47	87	132	165	199
SNOTEL					147	163	141

Julian Day of Maximum SWE

Terrain Height [m]

Simulation options

	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000-3500	3500-4500
Control	-6	-4	3	28	45	69	92
+Livneh albedo	+1	0	+1	+1	+7	+9	+8
+terrain	0	0	0	0	0	0	0
+Ch	-4	-2	+3	+4	+2	0	-2
+Max + z_0	+2	+3	+5	+8	+13	+11	+11
Total	-7	-3	12	41	67	89	109
SNOTEL					101	111	100

Maximum SWE [mm]

Terrain Height [m]

Simulation options	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000-3500	3500-4500
Control	10	11	16	66	190	355	481
+Livneh albedo	0	0	+1	+6	+22	+39	+36
+terrain	0	0	0	0	0	0	0
+Ch	+1	+2	+7	+14	+12	+13	+21
+Max + z_0	+1	+2	+5	+19	+49	+63	+66
Total	12	15	29	105	273	470	604
SNOTEL					544	677	540

Effect of Terrain Adjustment

Max SWE[mm] - no terrain adjustment

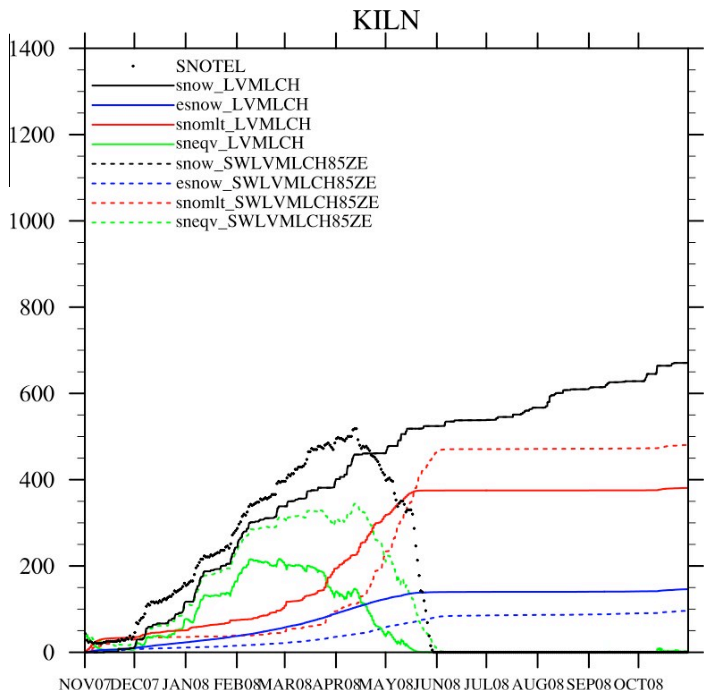
Slope (degrees)	N	E	S	W
0-2	29	25	29	35
2-4	113	103	113	100
4-6	162	147	173	147
6-8	173	167	204	156
8-10	179	171	221	160
10+	144	155	208	135

Difference[mm] with terrain adjustment

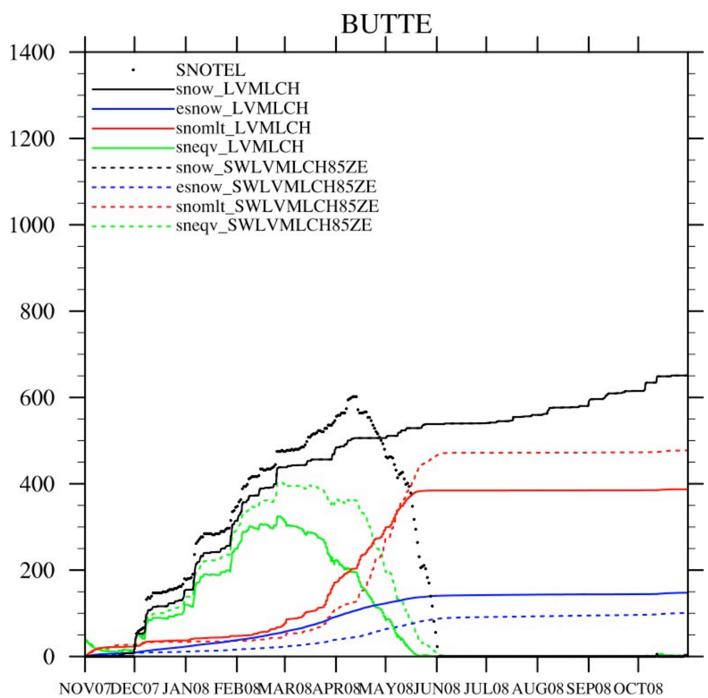
	N	E	S	W
0-2	+1	0	0	0
2-4	+3	0	-4	0
4-6	+7	+1	-7	0
6-8	+12	+1	-12	-1
8-10	+15	+2	-16	-1
10+	+13	0	-19	-2

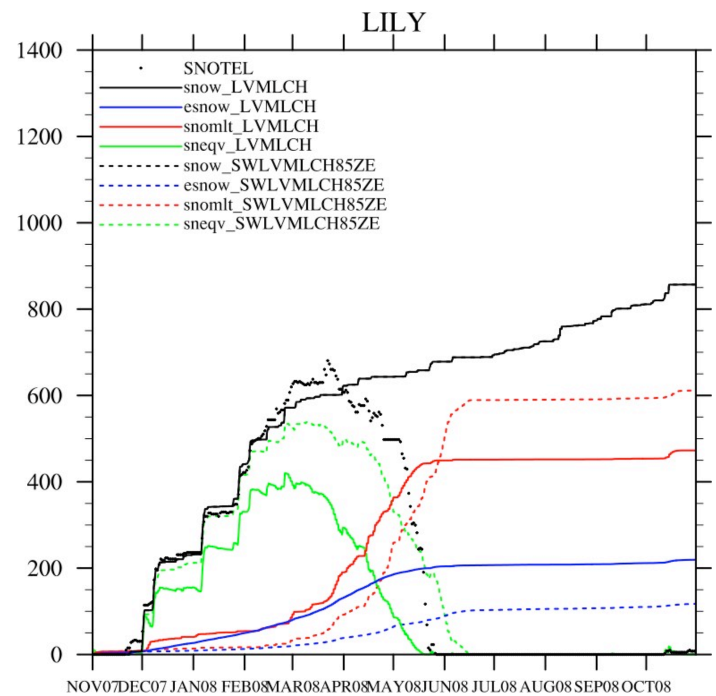
Combined effects with observed SW
Bad sites

Dash lines: Simulation with changes in Zo, albedo, GOES
Solid line: Default simulation(with new WRF Ch)



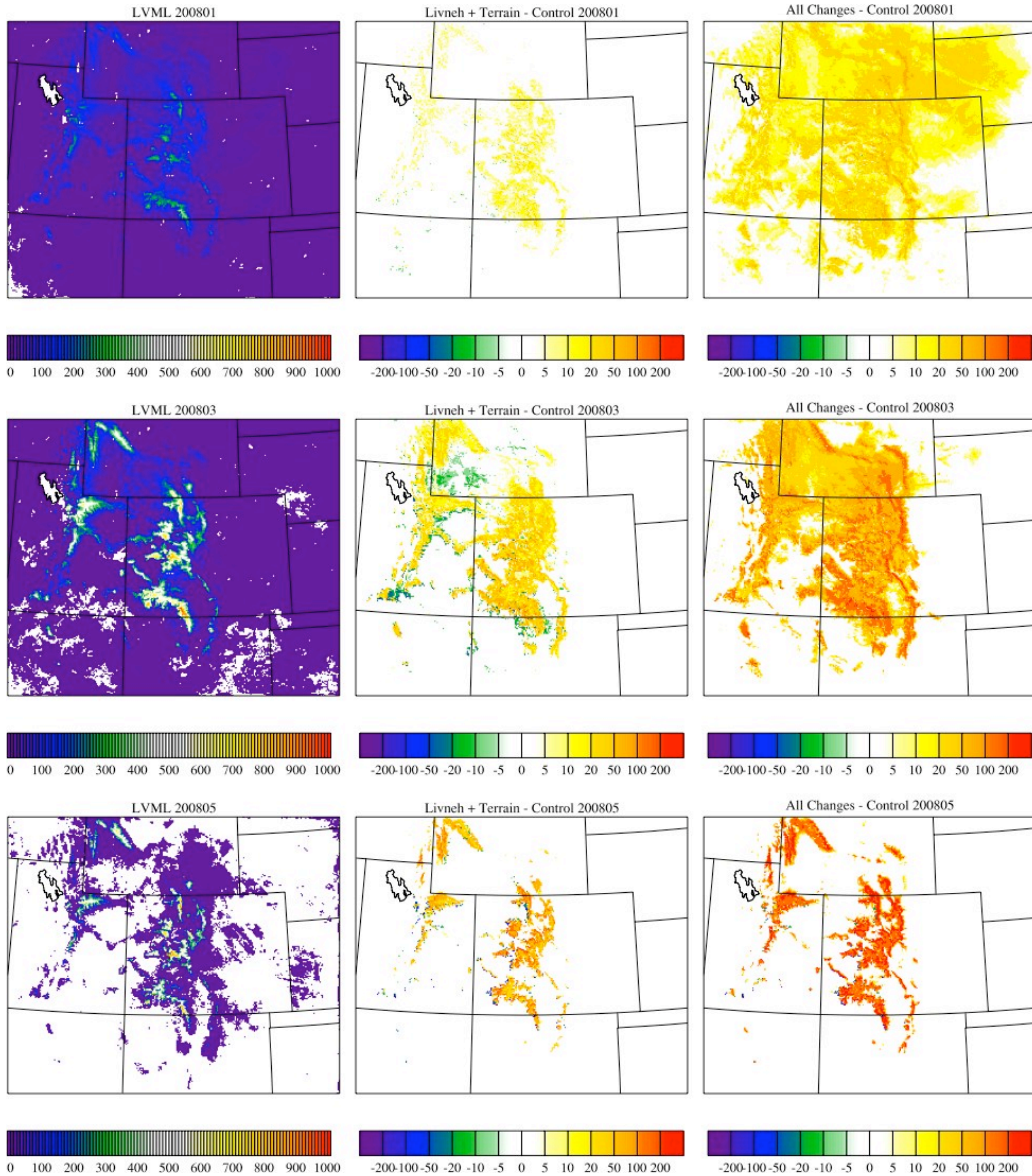
By reducing sublimation and early spring melt, these mods improves timing of snow melt season





<u>Legend legend</u>
LV: Livneh albedo
ML: model level forcing
CH: WRF MYJ stability
ZE: Zo = f(exposed veg)
85: Max albedo = 0.85
SW: GOES SW forcing

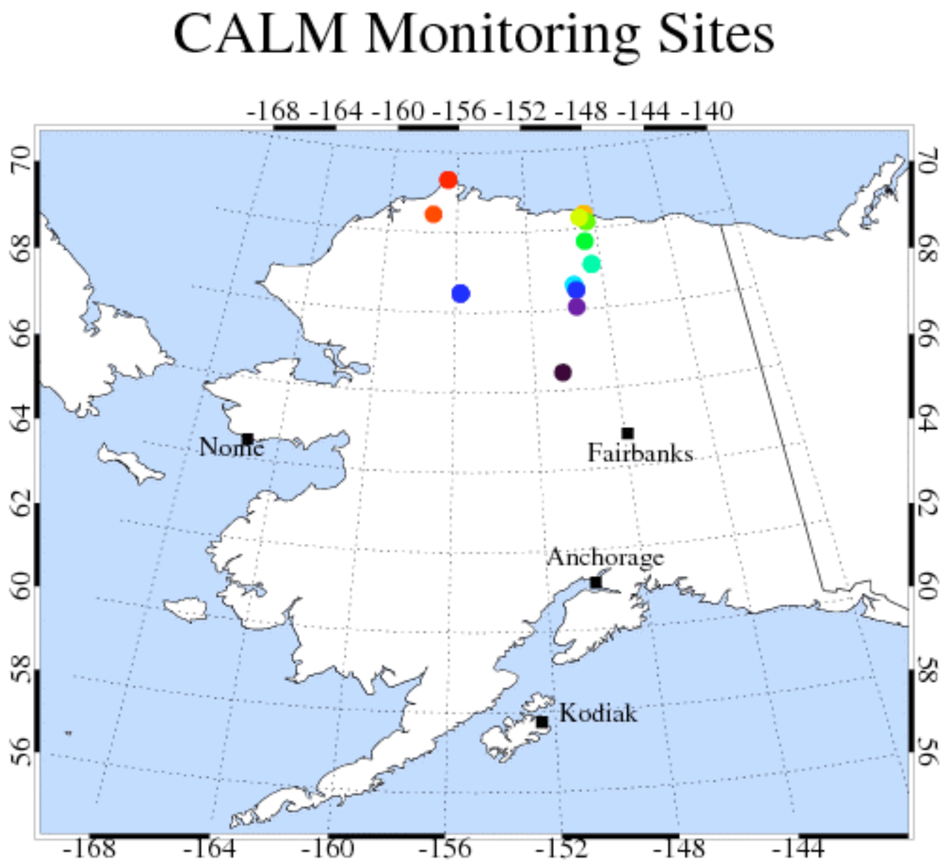
Full grid effects of stability adjustment and all changes

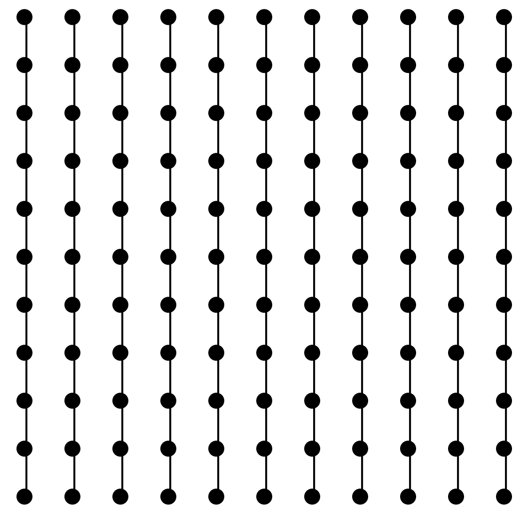


Left: Control
Middle: Control + Livneh + terrain
Right: Middle + Ch + albedo + Zo

Effects are domain-wide but increased time to melt does not propagate out of mountains

Active Layer Thickness Simulations
in support of the Arctic System Reanalysis





1km^2 measurement grid
with 121 points 100m apart

CALM: Circumpolar Active Layer Monitoring

Test Simulation Configurations

27-year (1980-2006) point simulations using HRLDAS over CALM measurement sites

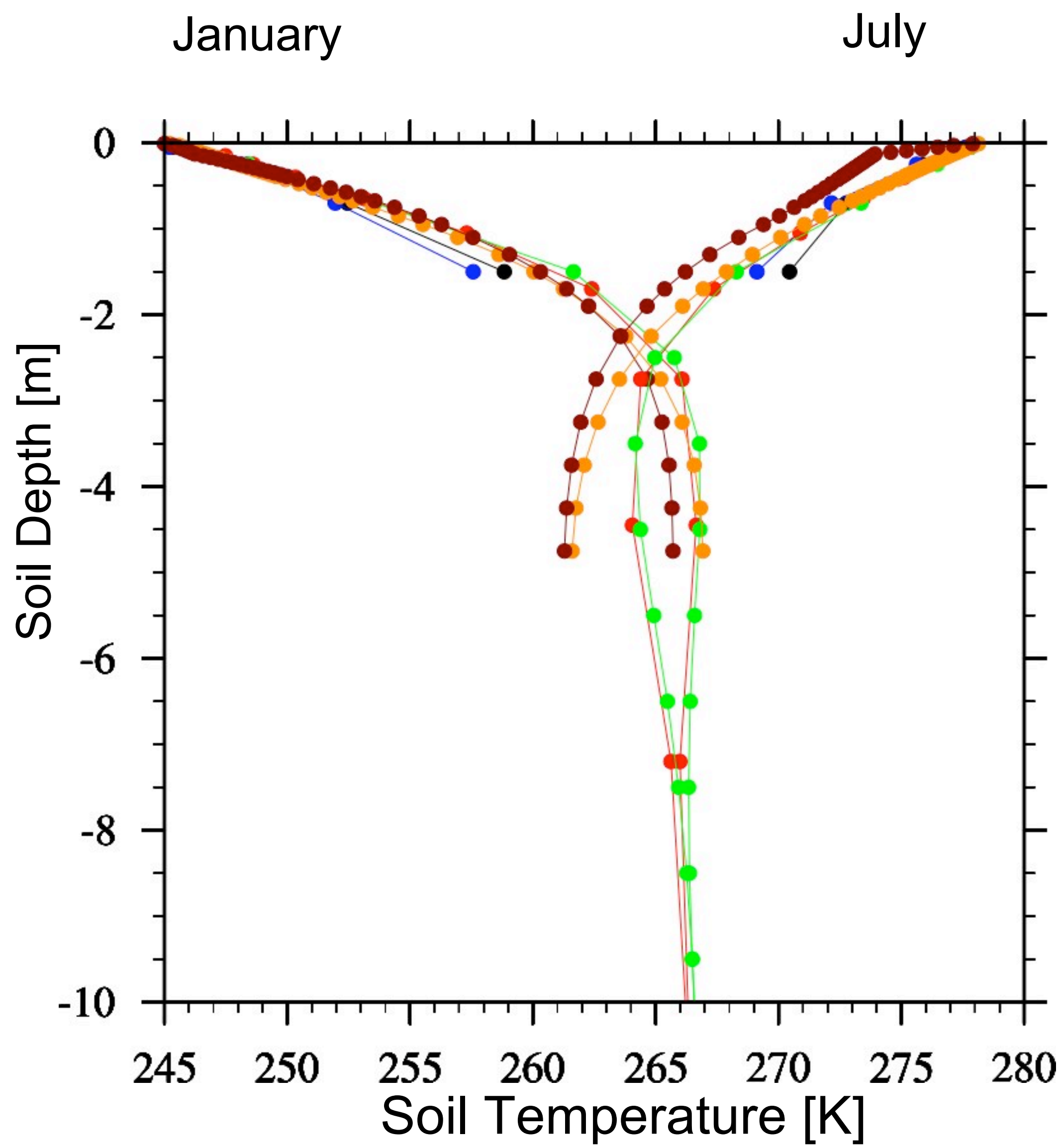
Forcing data: ERA-40 (1980-1999); JRA-25 (2000-2006)

```
control = 0.05,0.25,0.70,1.5
zeroflux = control + zero flux bottom
stagger = 0.05,0.15,0.25,0.40,0.65,1.05,1.70,2.75,4.45,7.20, 11.65,18.85
constant = 0.05,0.25,0.70,1.5,2.5,3.5,4.5,5.5,6.5,7.5, \
           8.5,9.5,10.5,11.5,12.5,13.5,14.5,15.5,16.5,17.5
highres = 0.01,0.03,0.05,0.07,0.09,0.11,0.13,0.15,0.17,0.19, \
          0.21,0.23,0.25,0.27,0.29,0.31,0.33,0.35,0.37,0.39, \
          0.425,0.475,0.525,0.575,0.625,0.675,0.75,0.85,0.95,1.1, \
          1.3,1.5,1.7,1.9,2.25,2.75,3.25,3.75,4.25,4.75
organic = highres + inclusion of organic layer(peat) in top 12cm
```

- Ability to have heterogeneous soils in Noah

Barrow Simulation: Temperature Profiles

Black: control
Blue: zeroflux
Red: stagger
Green: constant
Orange: highres
Brown-ish: organic



Barrow Simulation: Temperature Profiles

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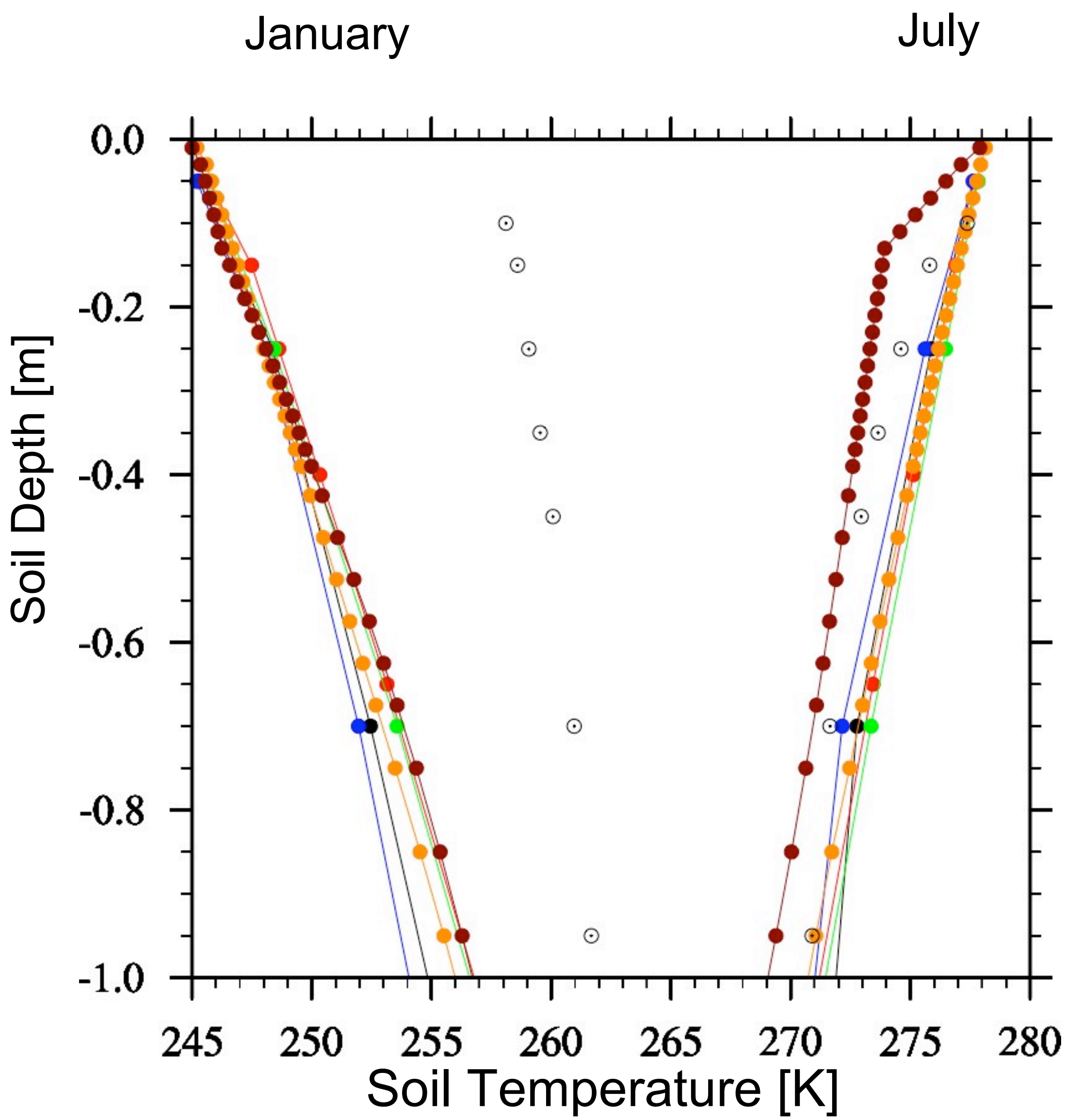
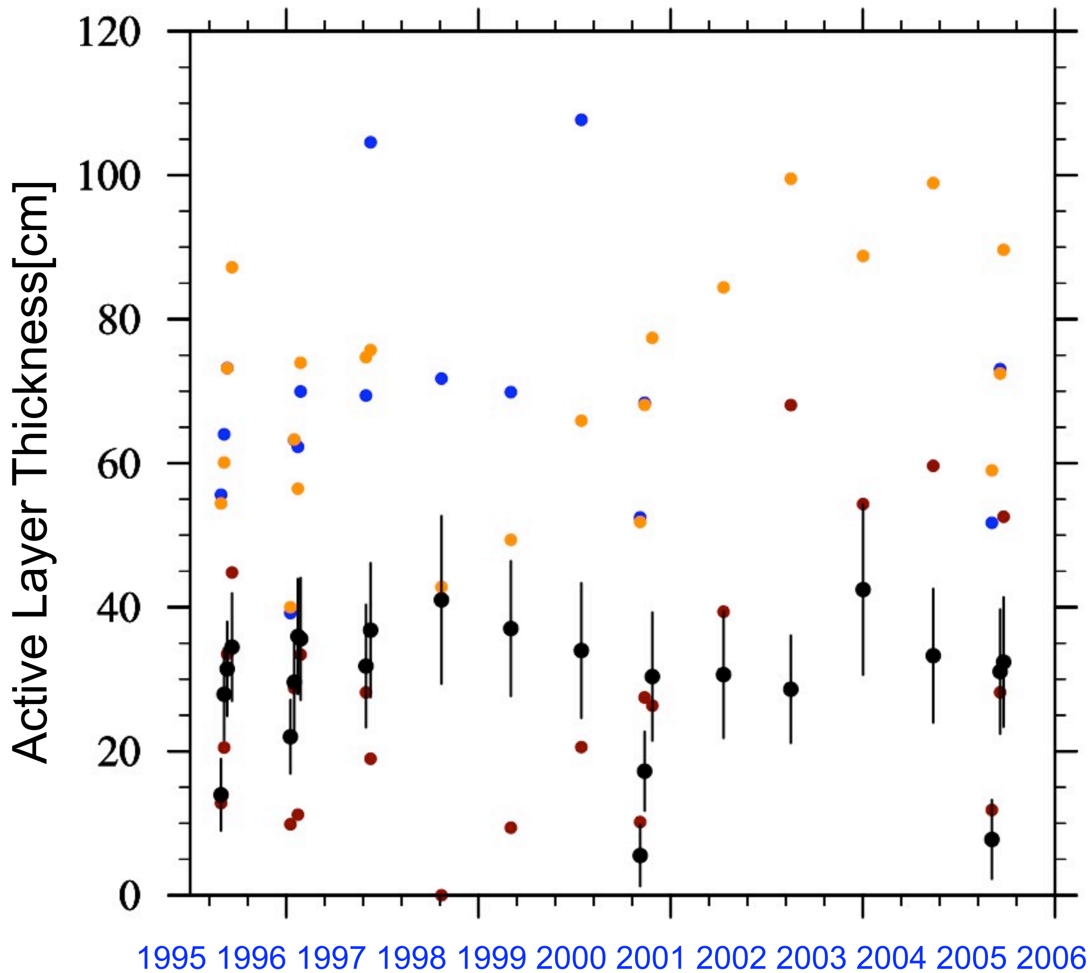


Barrow Simulation: Active Layer Thickness

Black: observations
Blue: control
Orange: highres
Brown-ish: organic

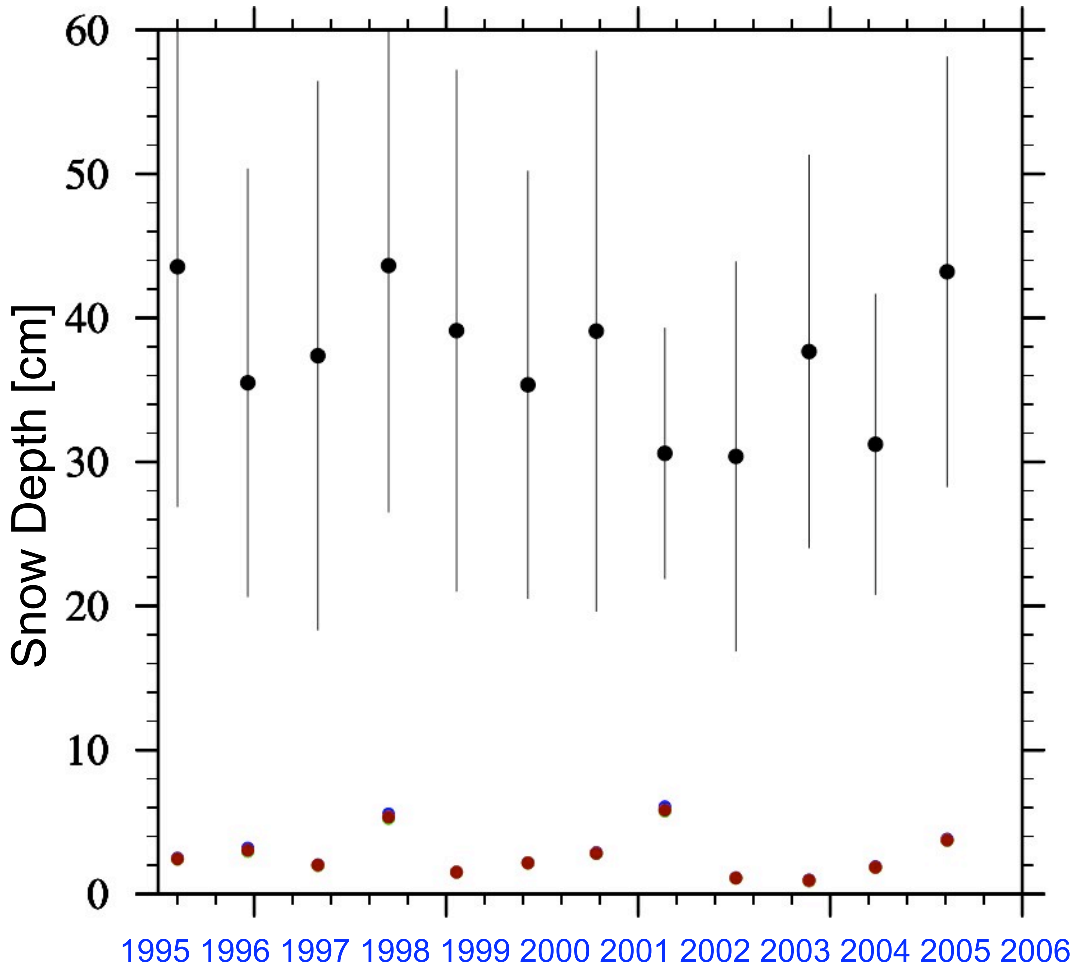
	Bias	RMSD
Control	57cm	63cm
Highres	41cm	44cm
Organic	-1cm	17cm



Point Simulation: Snow Depth

Black: observations
Blue: control
Brown-ish: organic

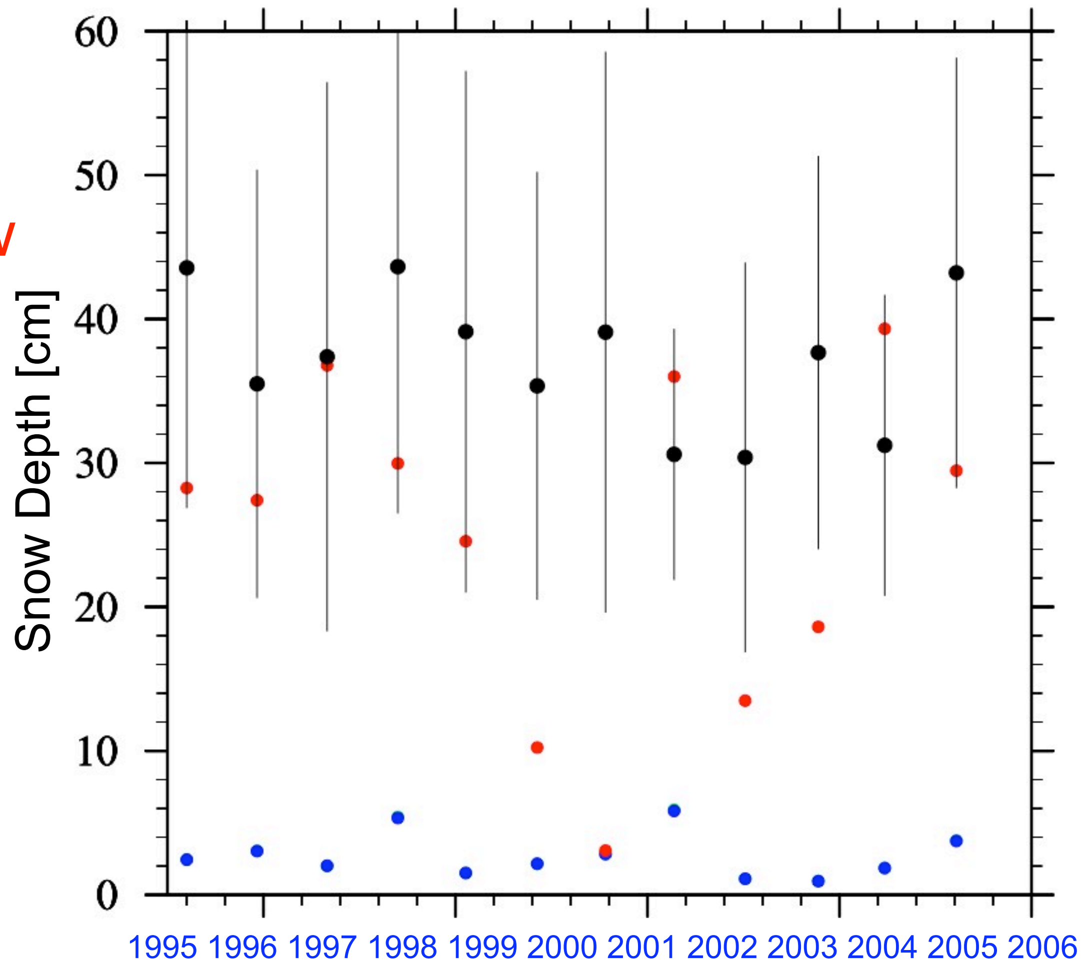
Snow depth much too low



Point Simulation: Snow Depth

Black: observations
Blue: control/organic
Red: z_0 adjusted for snow

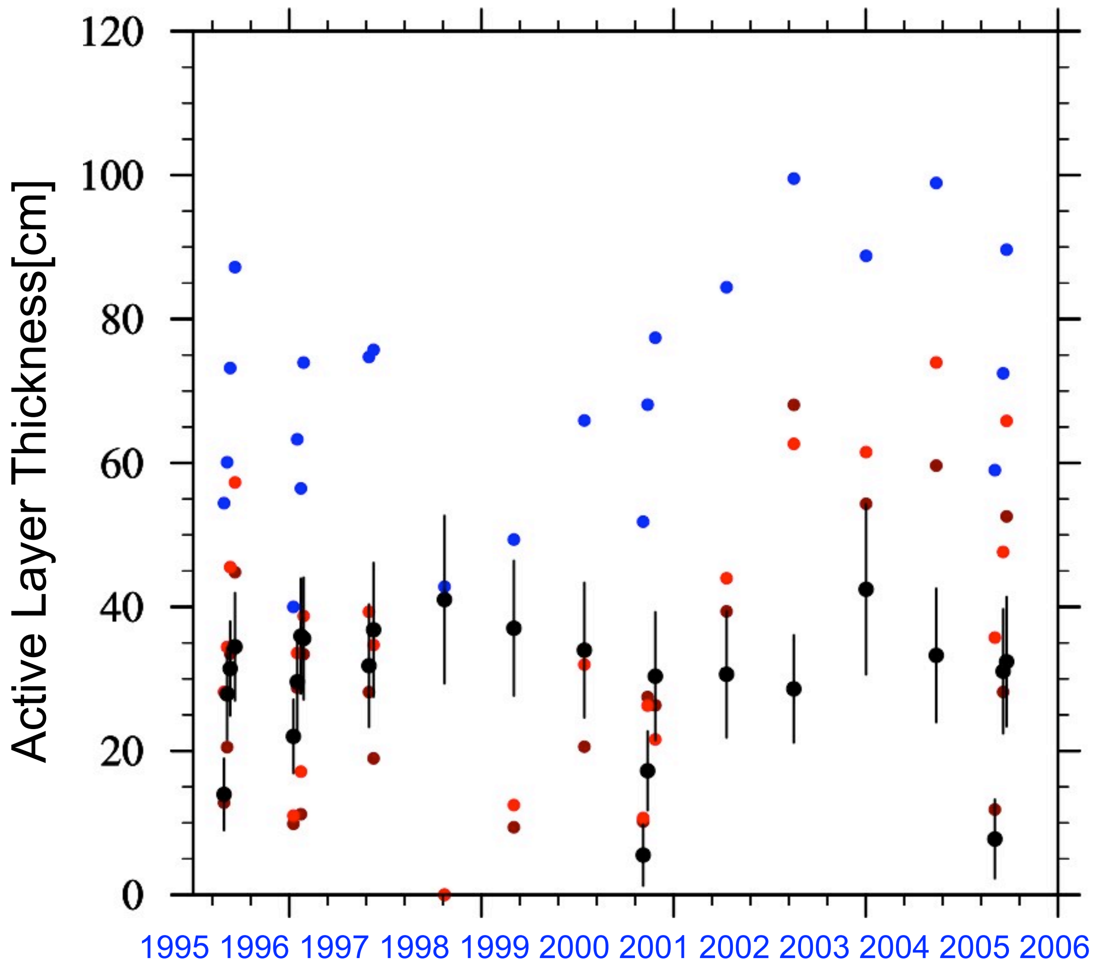
Changing z_o over snow covered tundra brings model in line with observations



Point Simulation: Active Layer Thickness

Black: observations
Blue: highres
Brown-ish: organic
Red: snow z_0

	Bias	RMSD
Highres	41cm	44cm
Organic	-1cm	17cm
Snow z_o	7cm	20cm

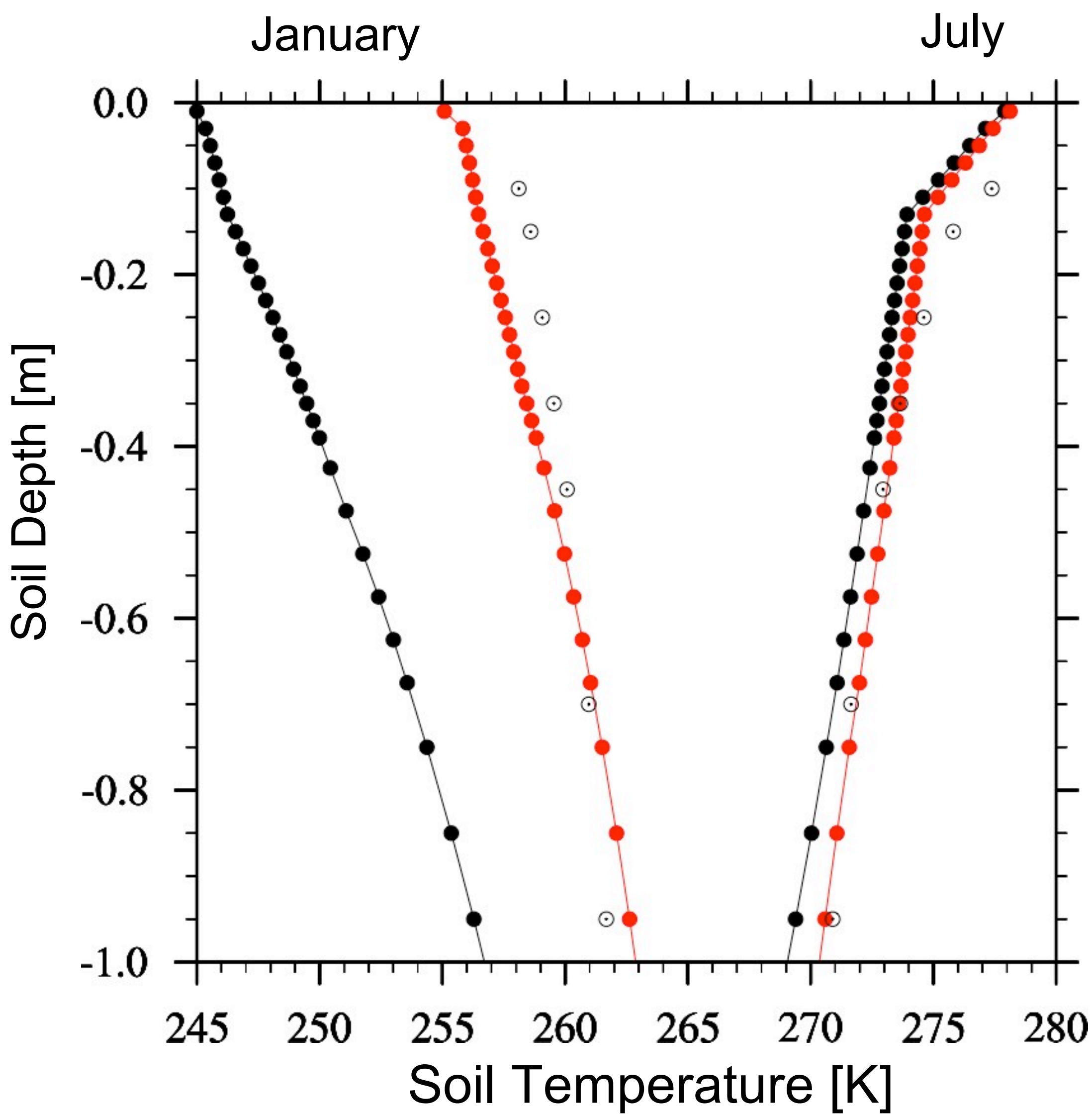


Point Simulation: Temperature Profiles

Black: organic

Red: snow z_o

Changing z_o improves snow, and hence temperature, simulation in winter and does not affect summer significantly



Summary

- Tested changes to Noah model to improve performance compared to SNOTEL and CALM observations
- Improvements are made in length of snow season, date of maximum SWE, and maximum SWE
- However, more improvements can still be made
- The addition of an organic layer greatly improves prediction of active layer depth
- Better snow simulation also improves winter temperature profiles