An Investigation of Liquid Water Percolation and Model Transferability in Multiple Snow Climates

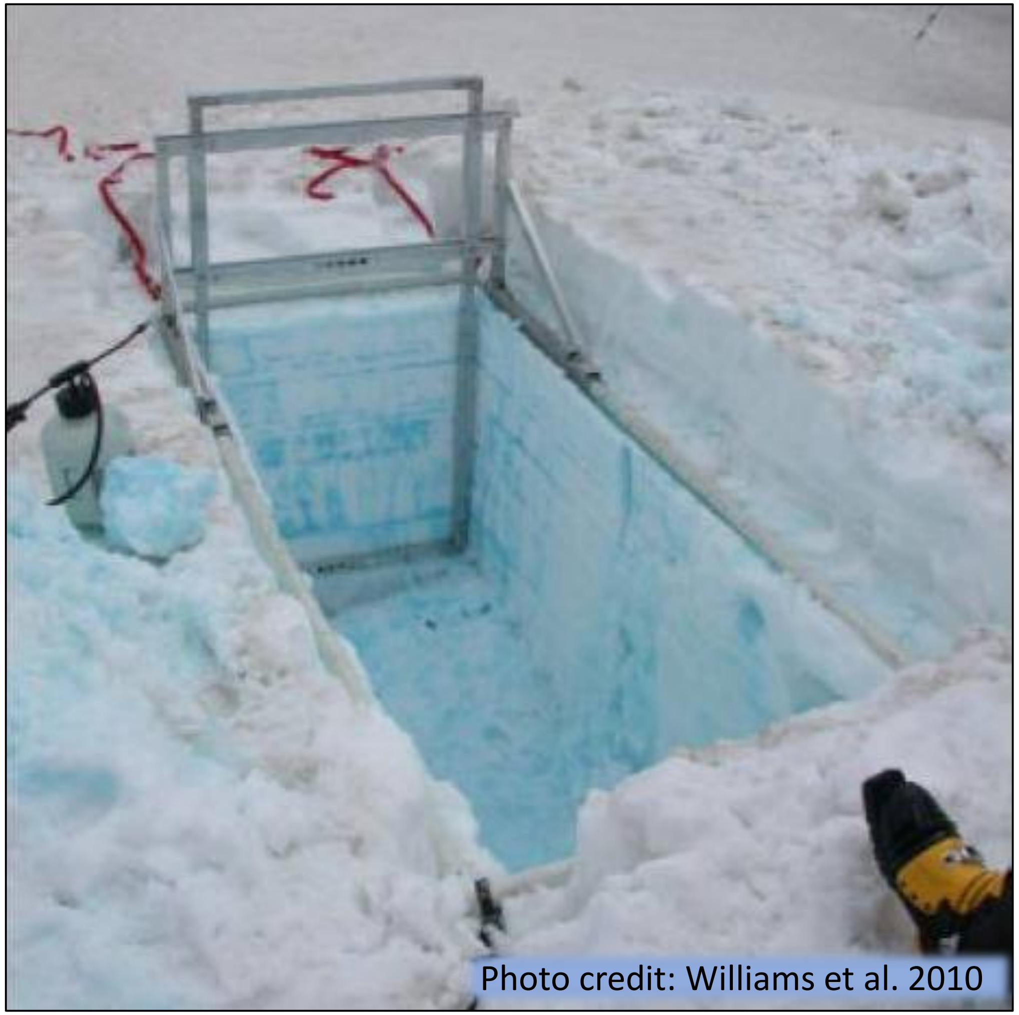


Photo credit: Williams et al. 2010

Photo credit: Howard Conway

Valle Scholarship

FUTURE PARK LEADERS of EMERGING CHANGE

Justin Pflug, University of Washington, Civil and Environmental Engineering

AMS 99th Annual Meeting: January 7, 2019

Snow runoff and model deviation

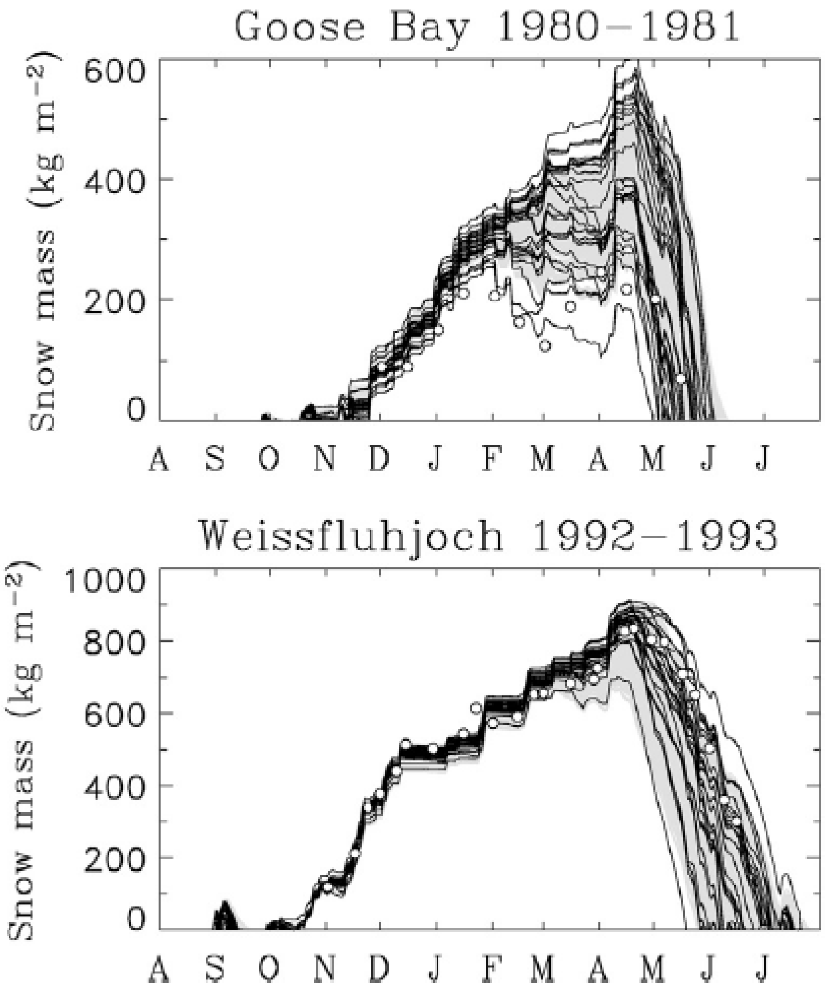


Figure from: Essery et al. (2013)

Snow runoff and model deviation

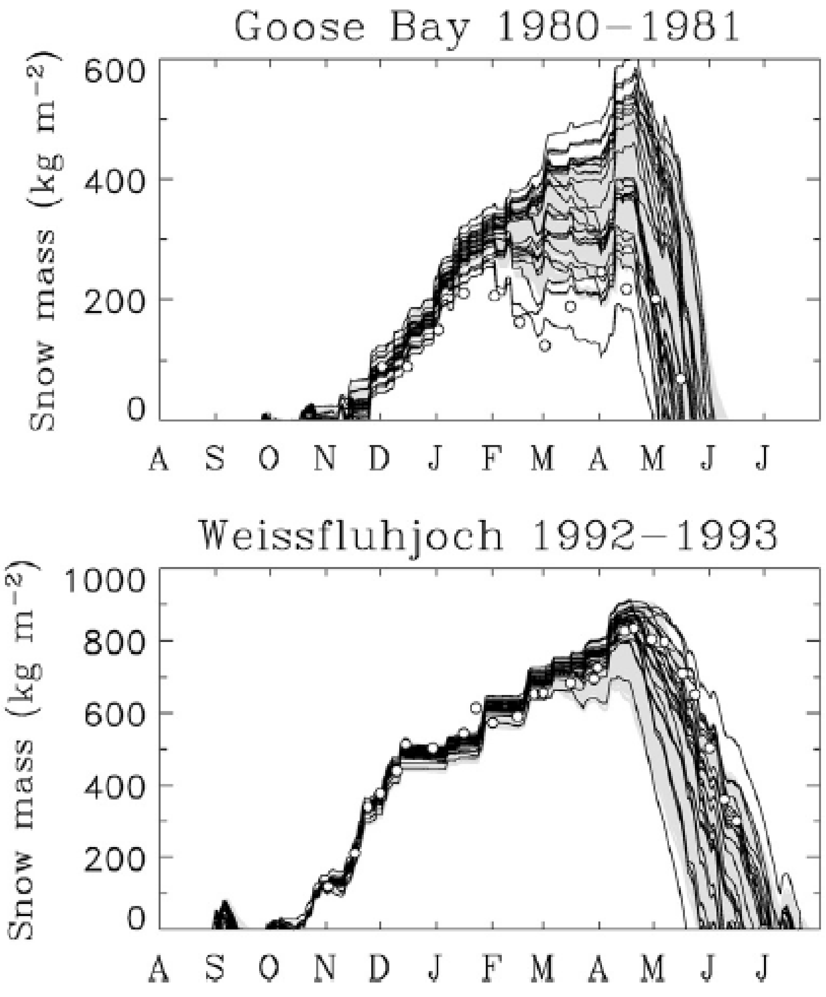


Figure from: Essery et al., (2013)

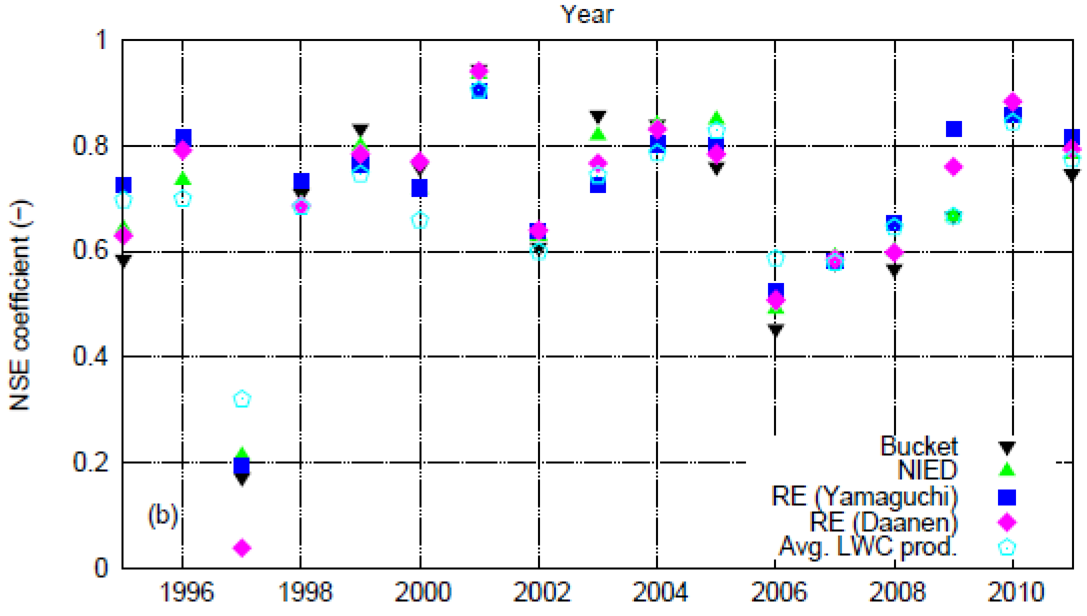
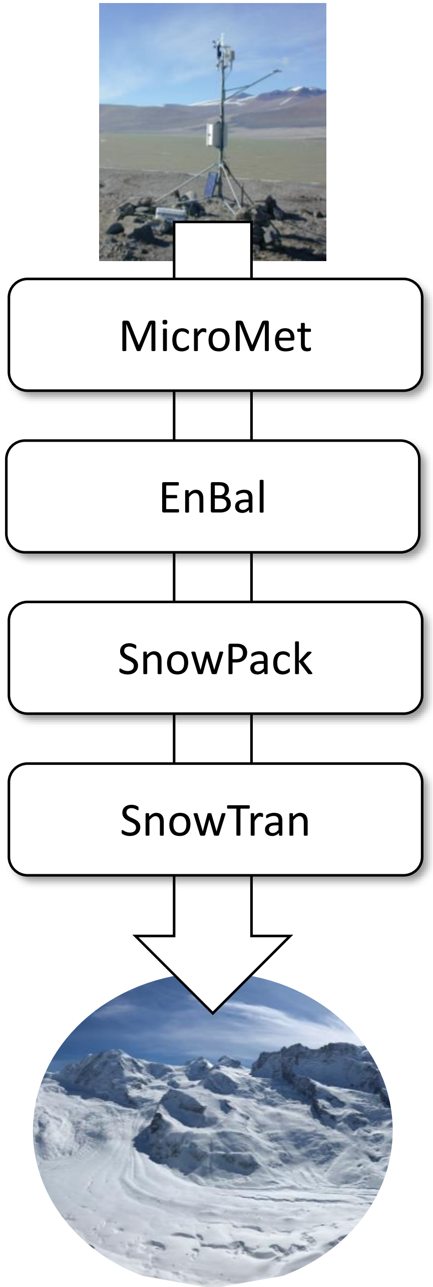


Figure from: Wever et al. (2014)

SnowModel (Liston and Elder, 2006)



MicroMet

EnBal

SnowPack

SnowTran

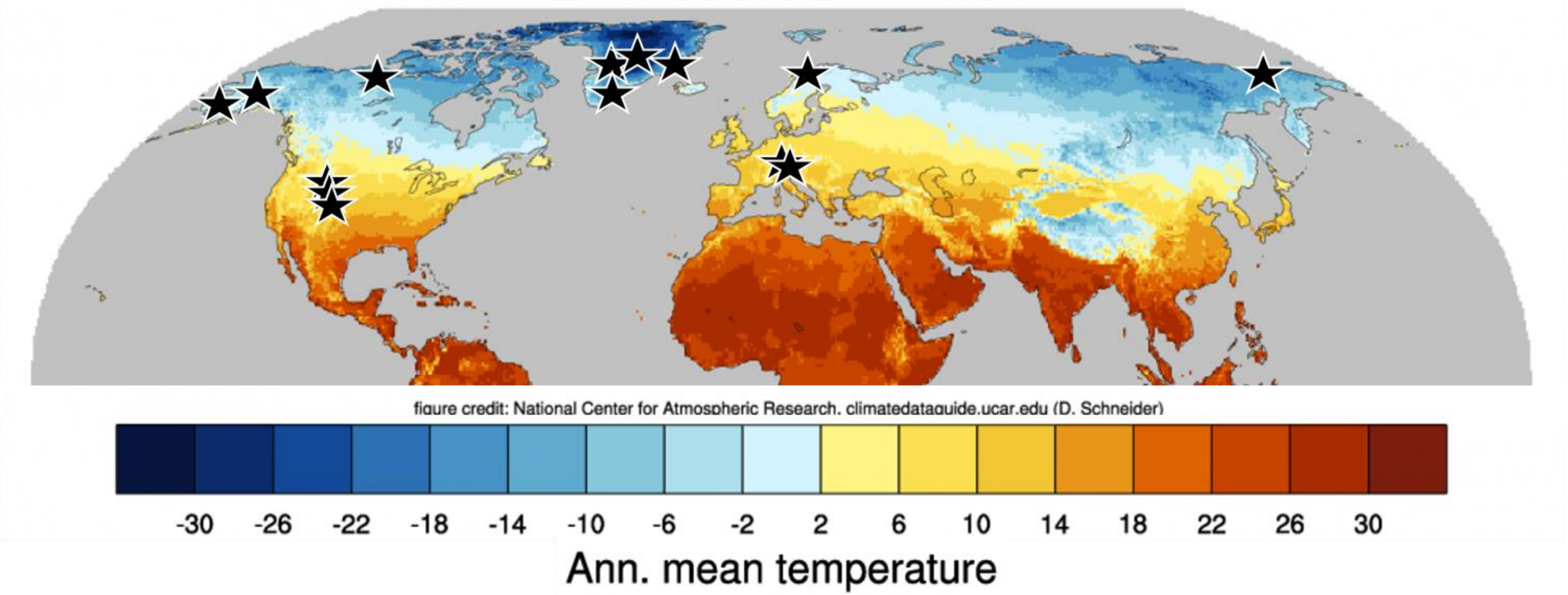
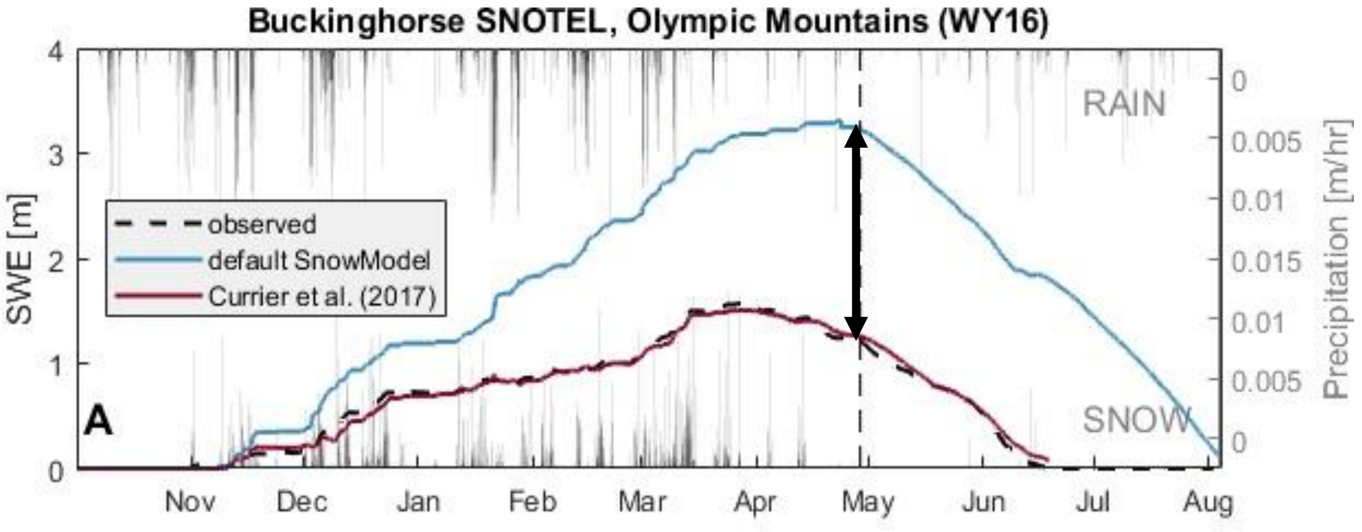

-30
-26
-22
-18
-14
-10
-6
-2
2
6
10
14
18
22
26
30
Ann. mean temperature

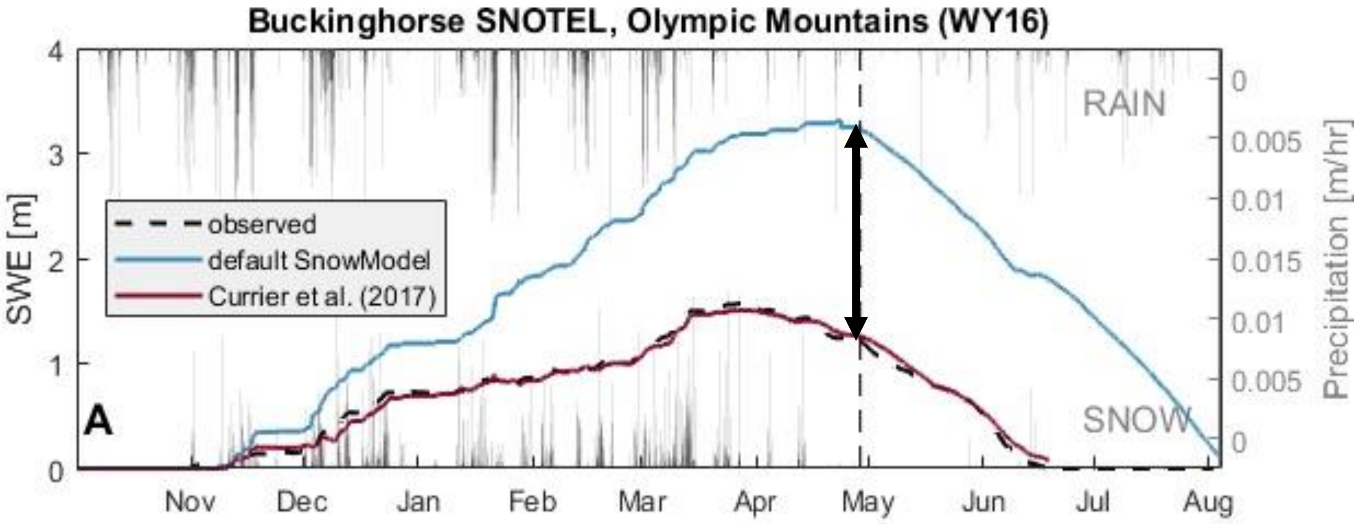
figure credit: National Center for Atmospheric Research, climatedataguide.ucar.edu (D. Schneider)

SnowModel Olympic Mountain maritime climate

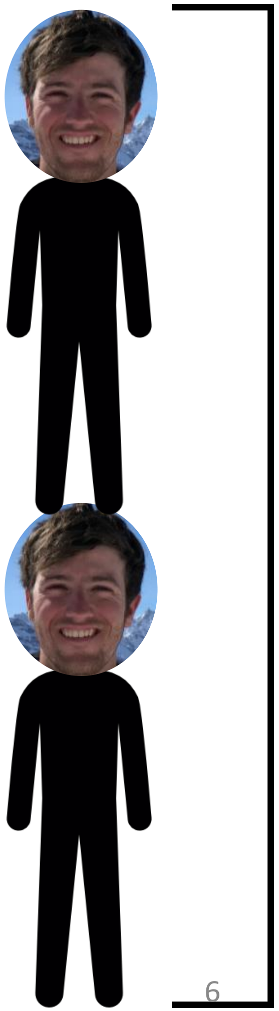


190 cm of difference in SWE (~3.8 m in snow depth)

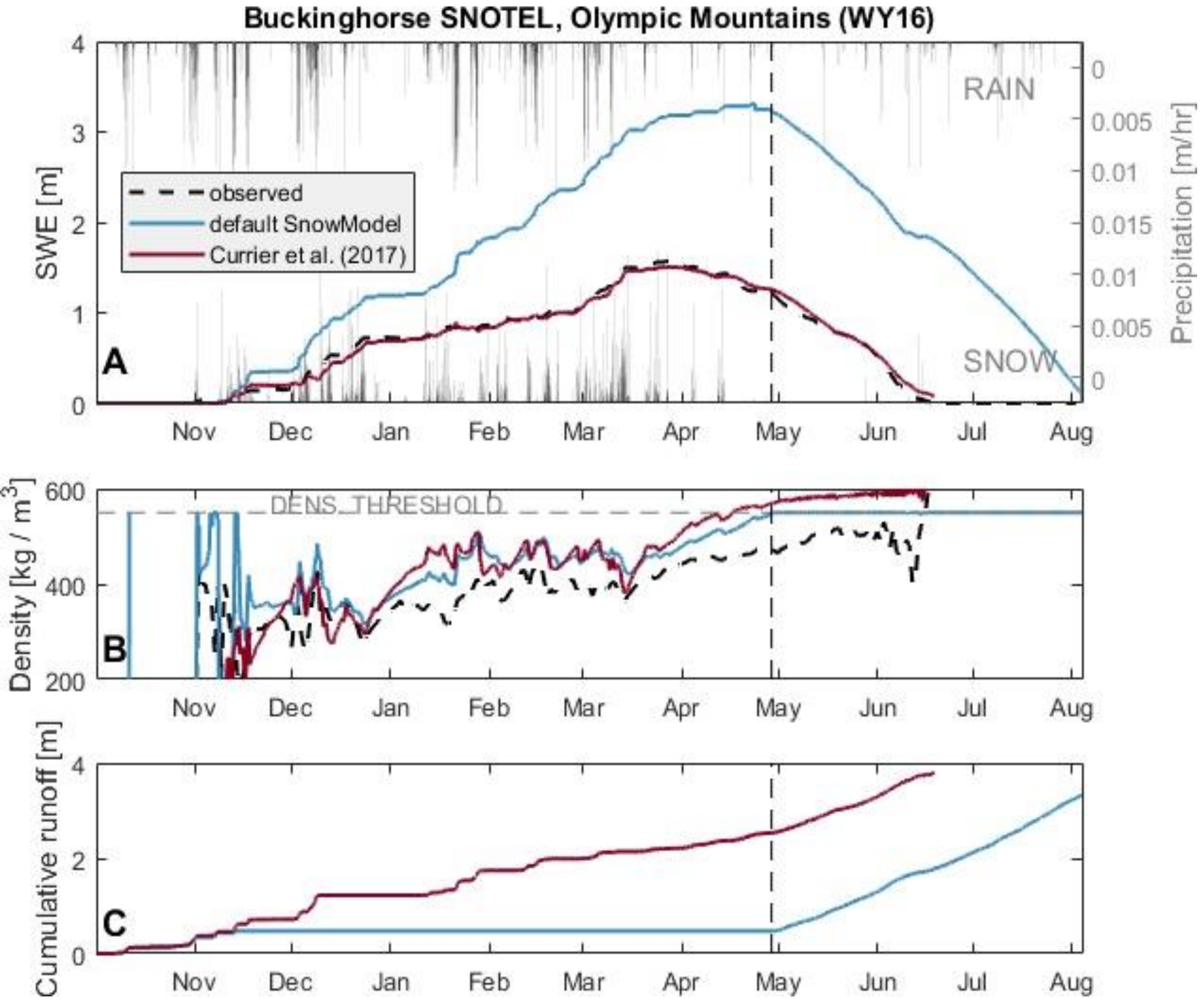
SnowModel Olympic Mountain maritime climate



190 cm of difference in SWE (~3.8 m in snow depth)



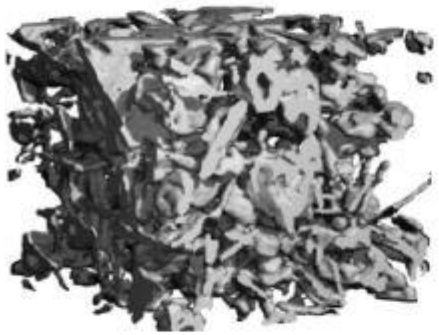
SnowModel Olympic Mountain maritime climate



Research Questions

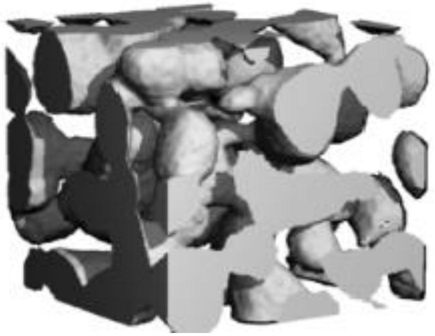
1. How sensitive is SnowModel snowpack evolution to different percolation decisions and parameterizations?
2. How transferable are different percolation routines between climates and what does this transferability mean?
3. Can overall model performance be improved for all climates?

Model adaptation

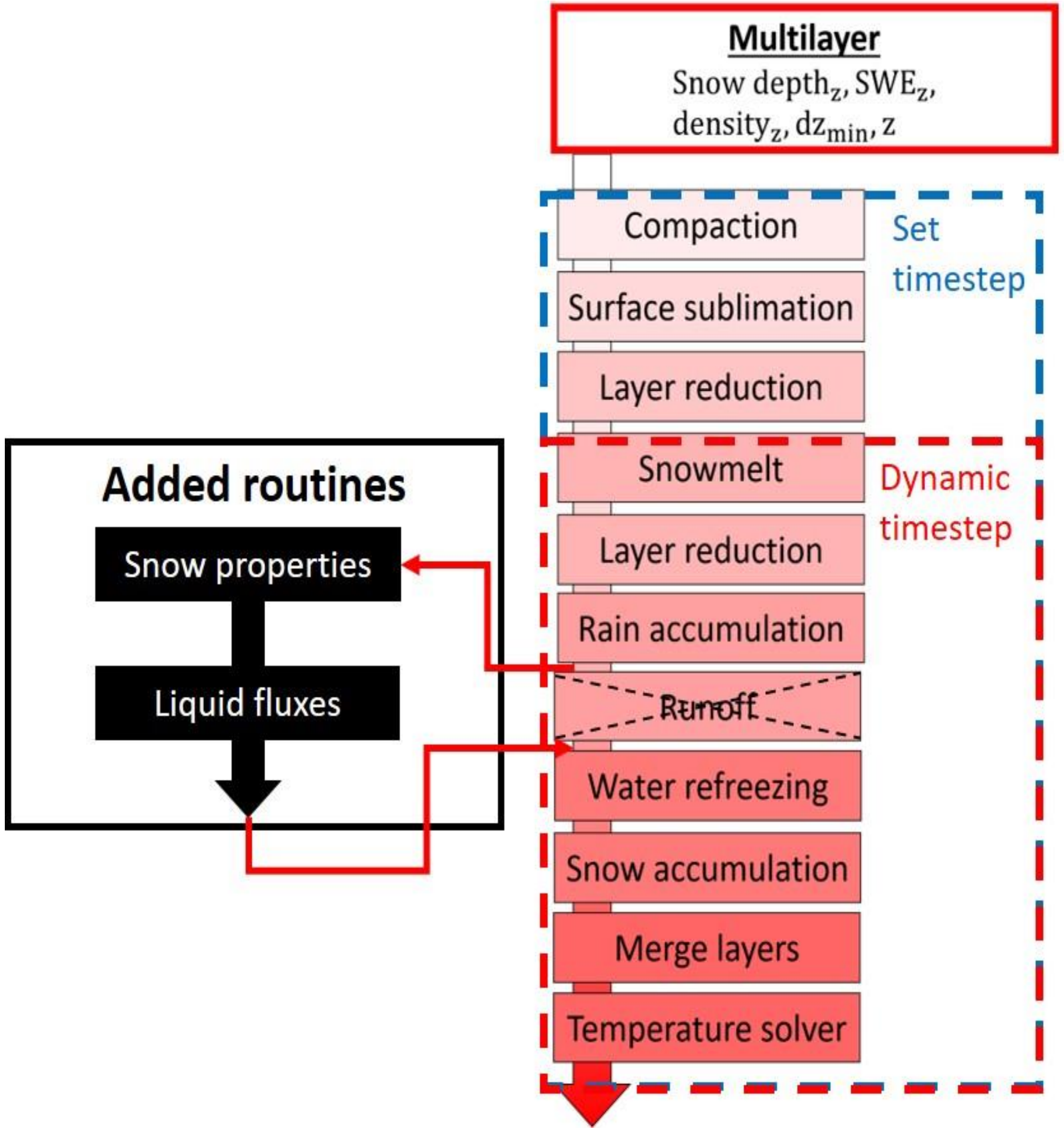


Cold, dry snow

From Thomas Kaempfer, SLF



Warm, wet snow



Added routines

Snow properties

Liquid fluxes

Multilayer

Snow depth$_z$, SWE$_z$, density$_z$, dz$_{min}$, z

Set timestep

Compaction

Surface sublimation

Layer reduction

Dynamic timestep

Snowmelt

Layer reduction

Rain accumulation

~~Runoff~~

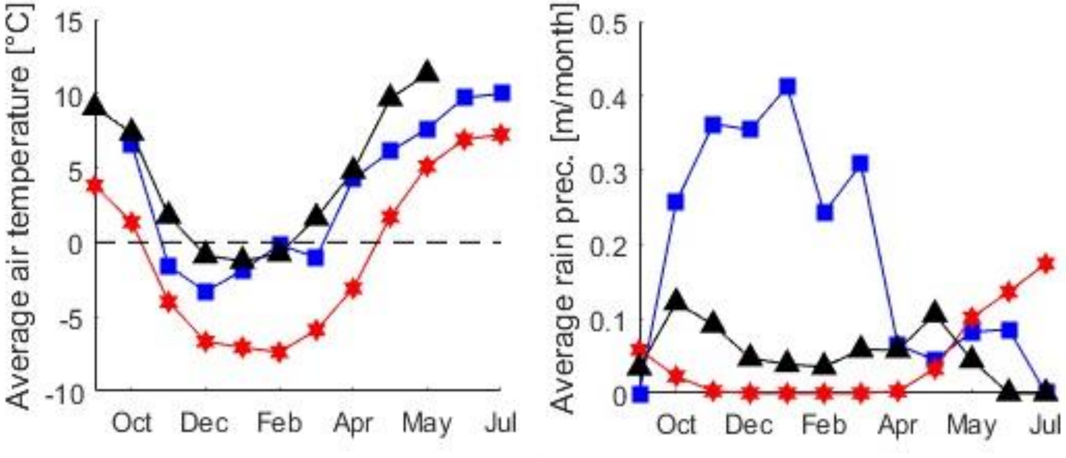
Water refreezing

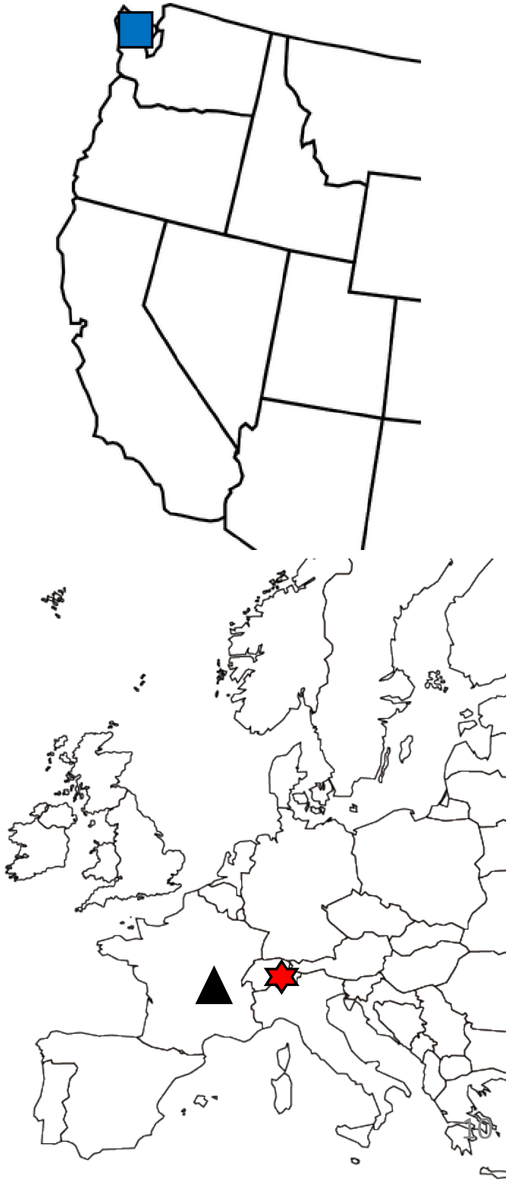
Snow accumulation

Merge layers

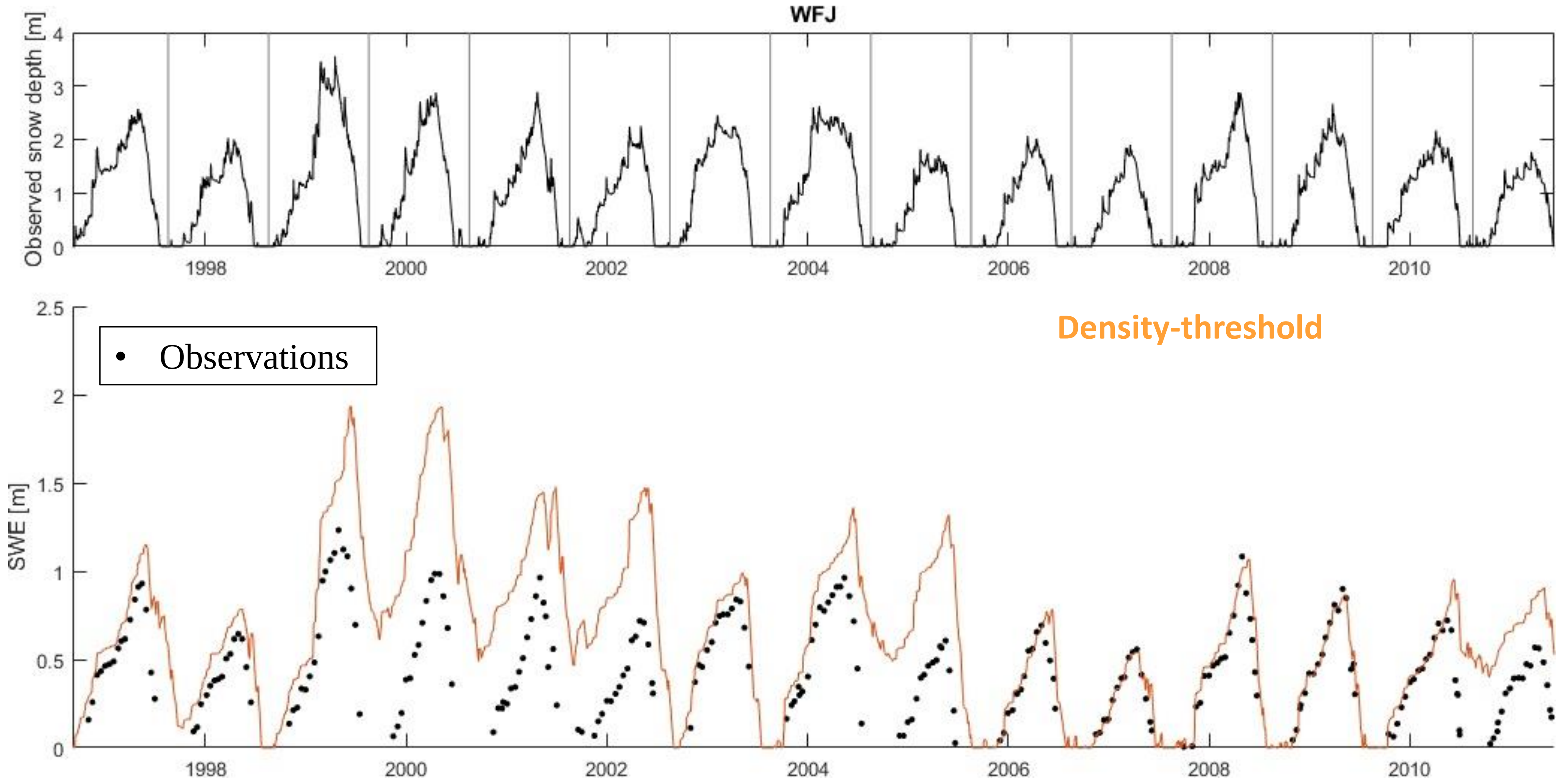
Temperature solver

Study domains

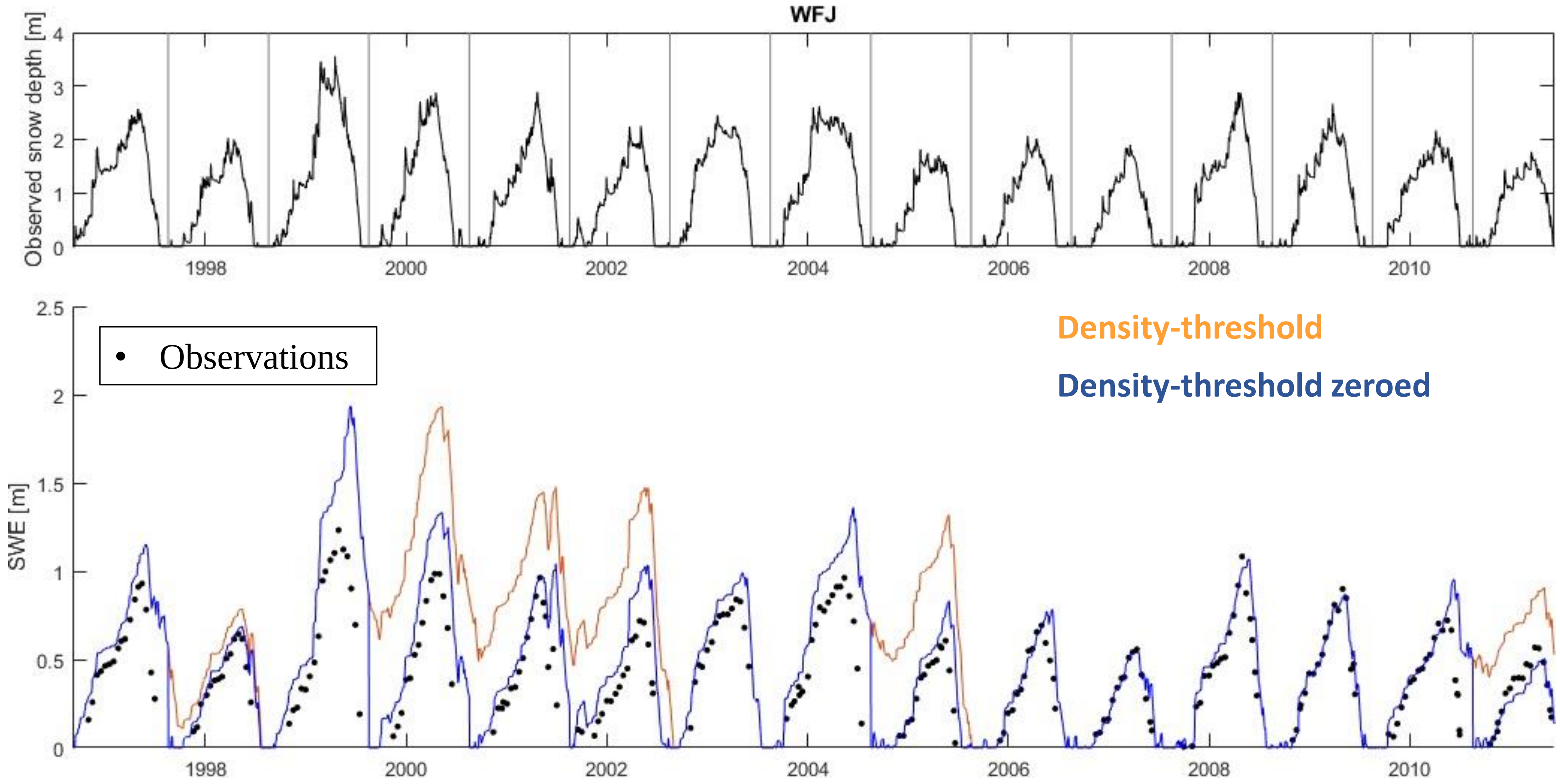




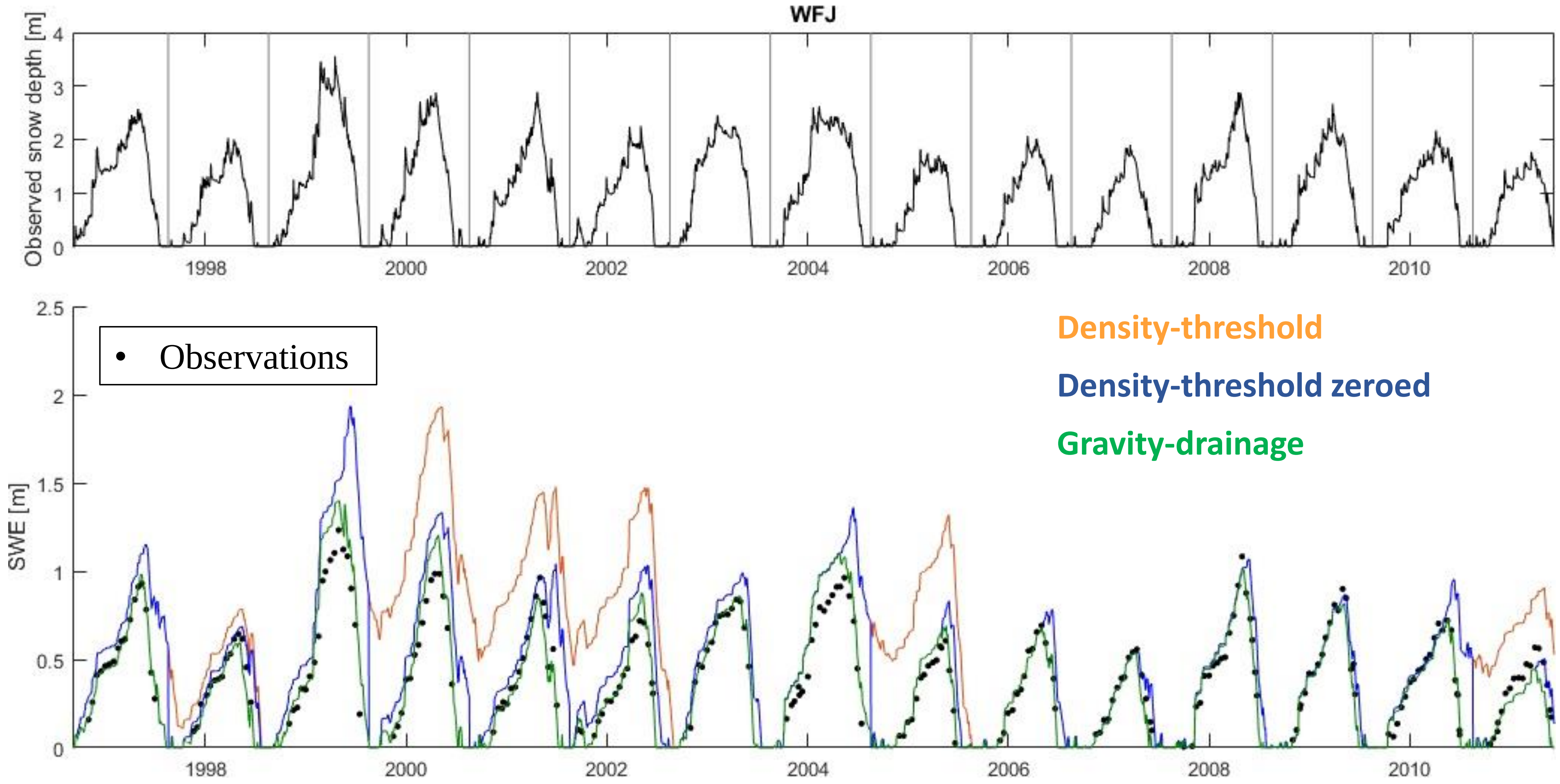
Default simulations



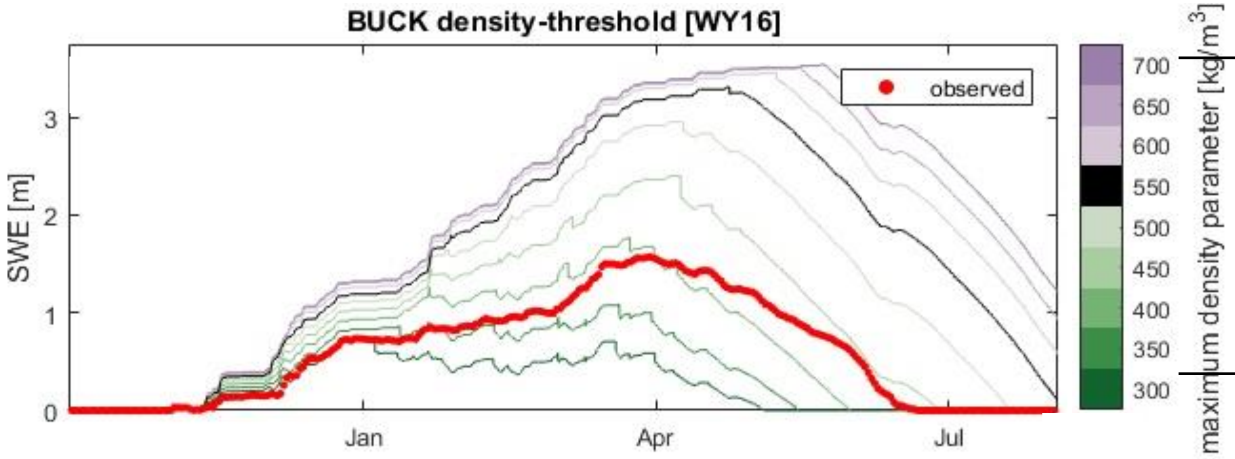
Default simulations



Default simulations



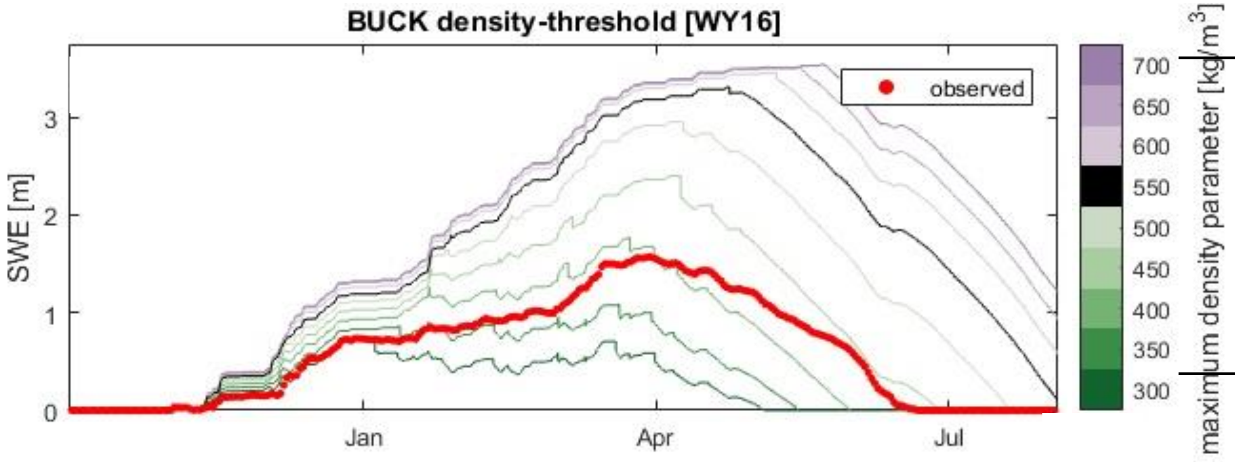
Default simulations and parameter sensitivity



Value used to identify modeled ice layers (Wever et al. 2016)

Used to calibrate SnowModel in Oregon cascades (Sproles et al. 2013)

Default simulations and parameter sensitivity



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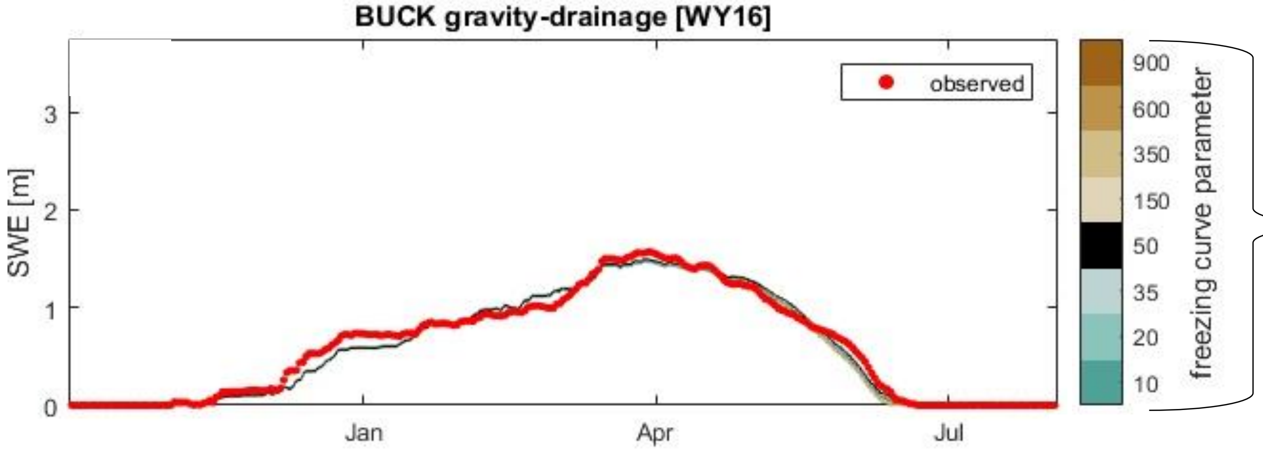
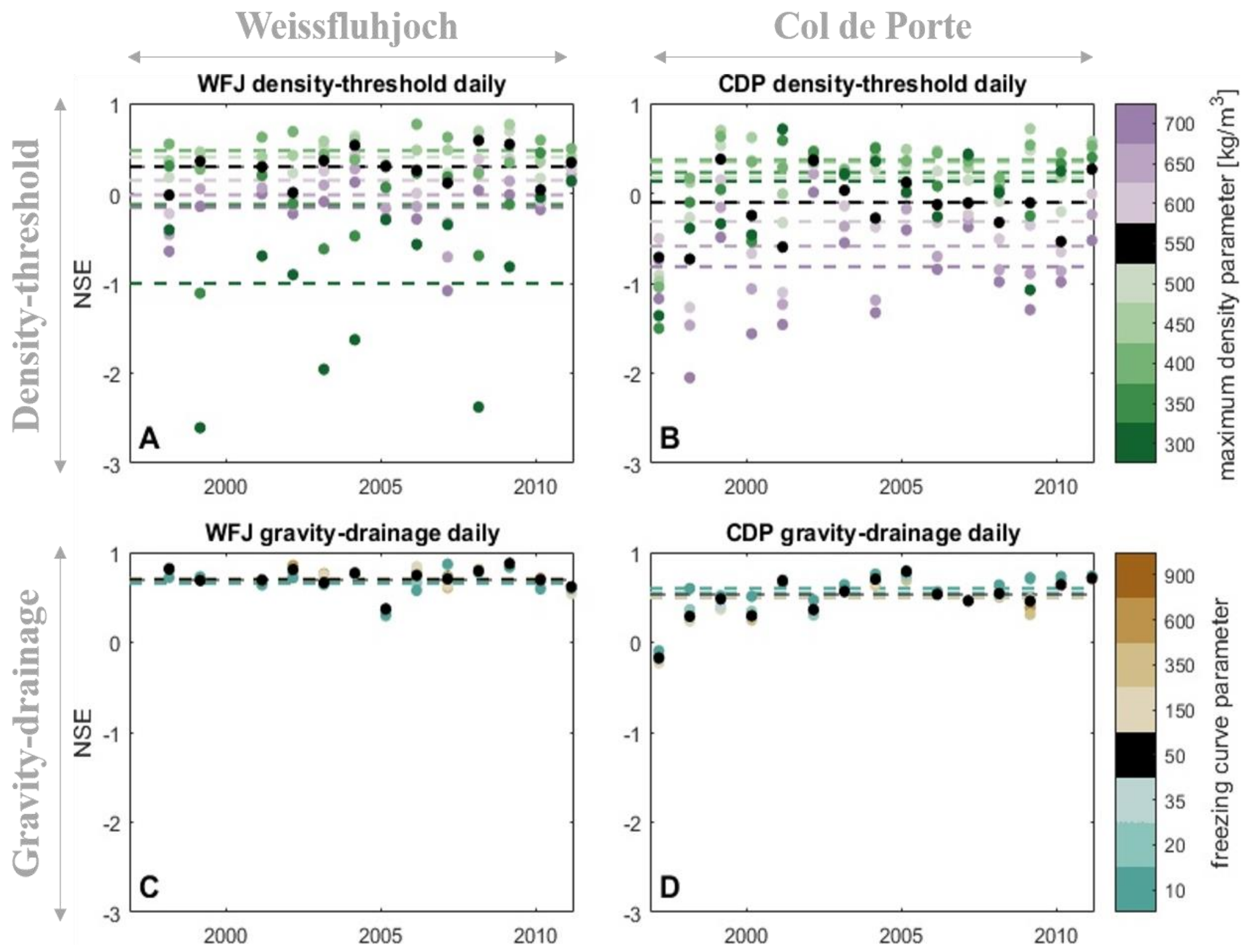


Recommended parameter bounds.
Used to define the curve between snow temperature and liquid water content.

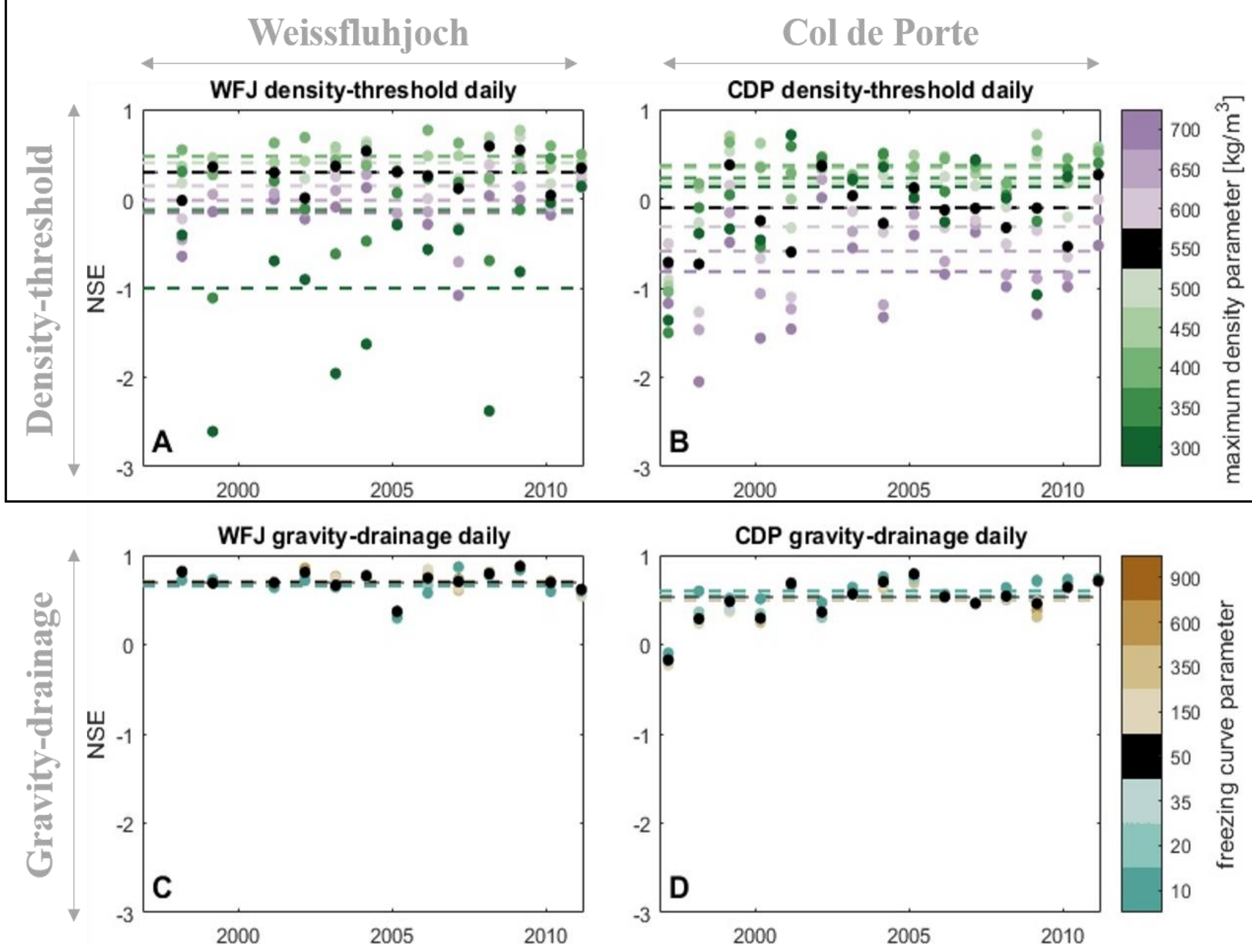
Default simulations and parameter sensitivity



● = Annual NSE

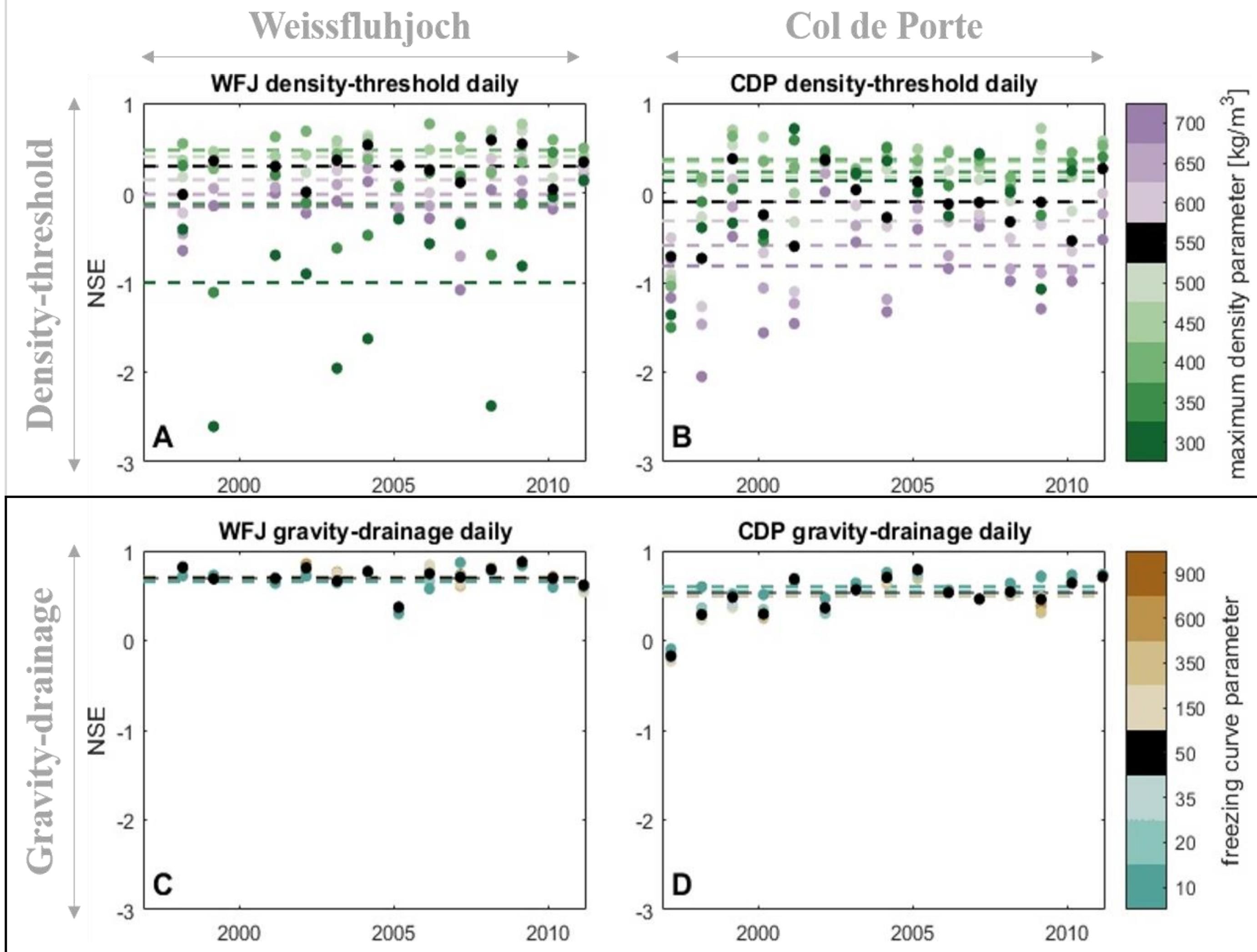
▬ ▬ ▬ = Total NSE

Default simulations and parameter sensitivity



- High sensitivity
- 15% > 0.5 NSE
- 52% < 0.0 NSE

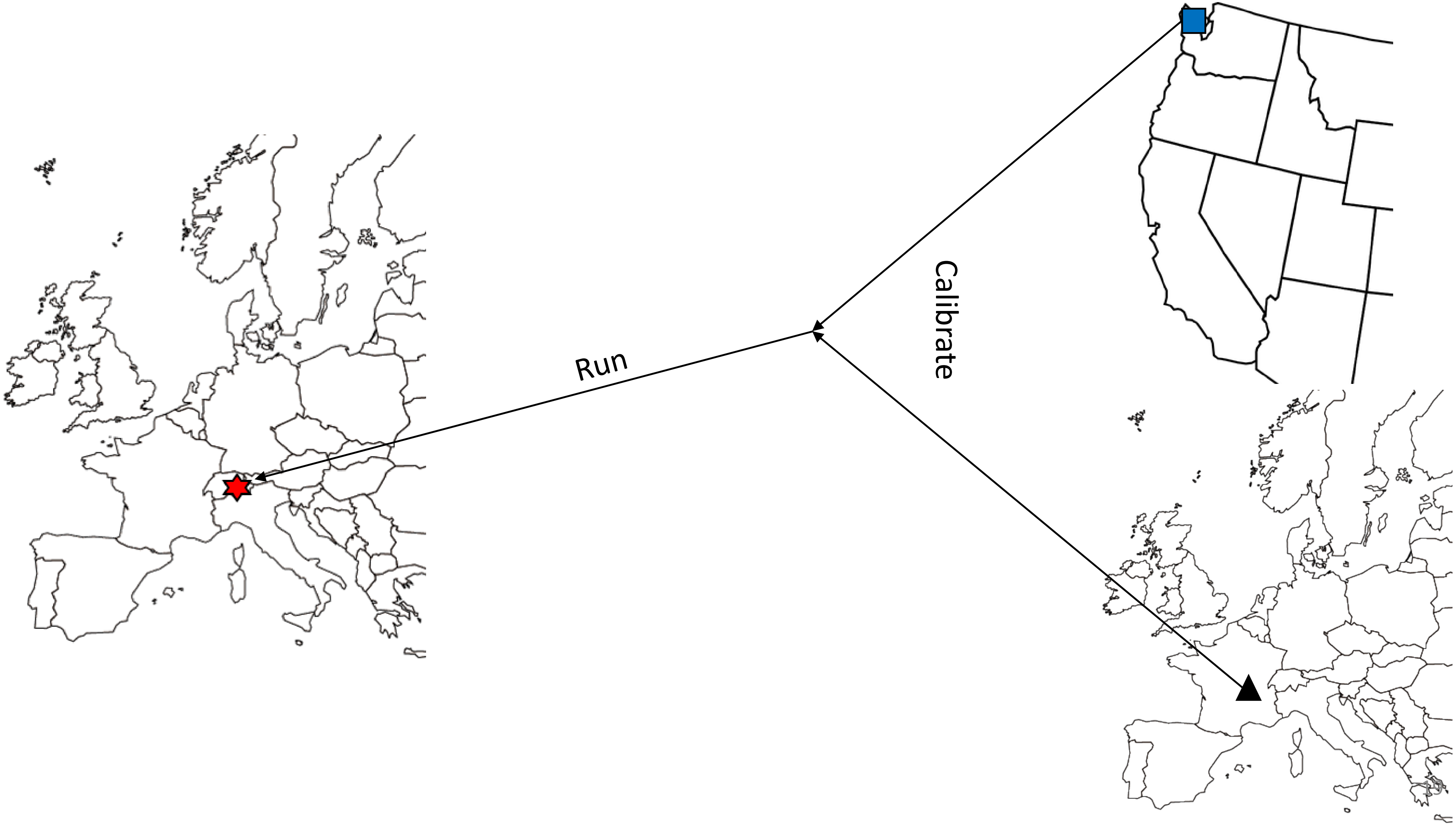
Default simulations and parameter sensitivity



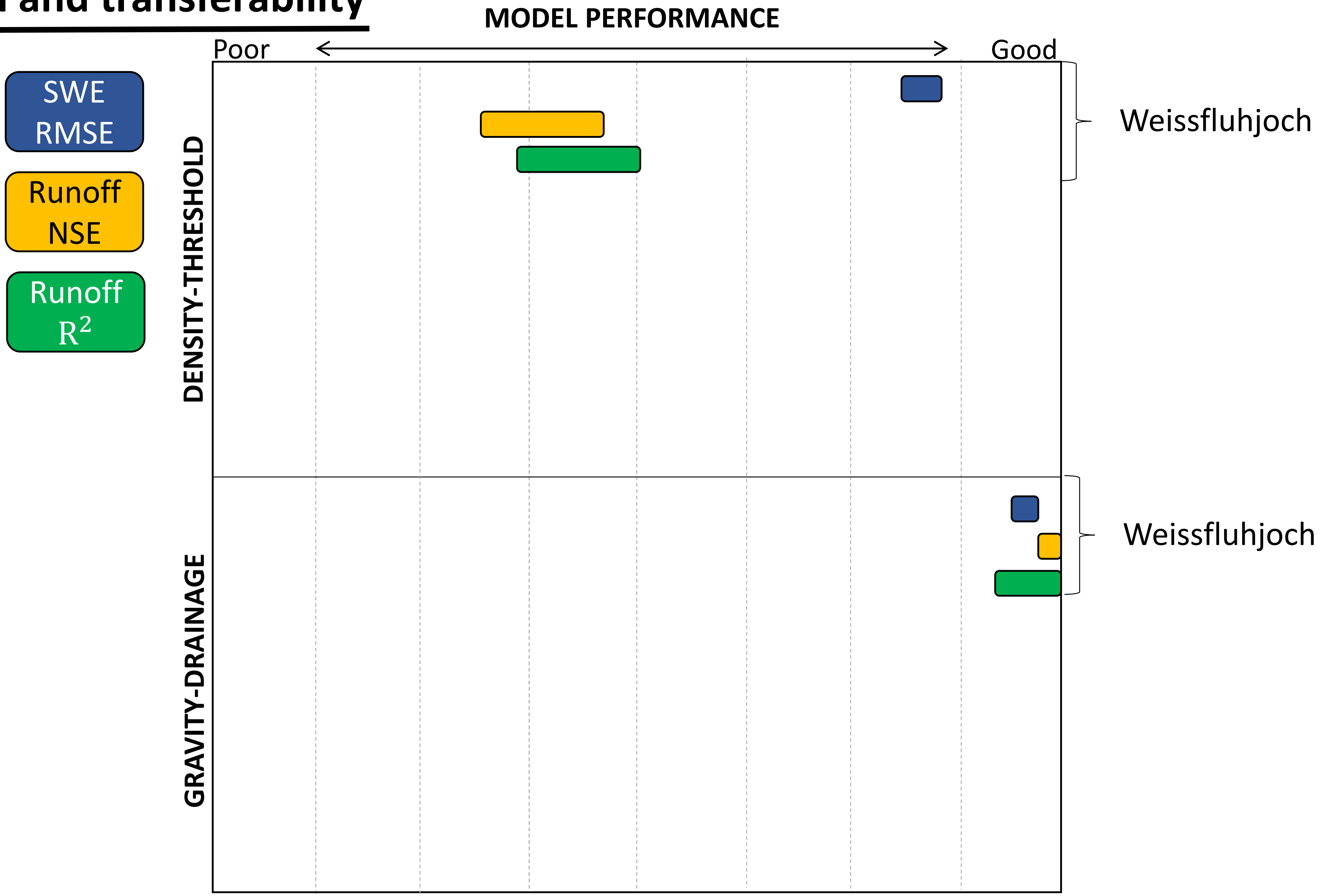
- High sensitivity
- 15% > 0.5 NSE
- 52% < 0.0 NSE

- Low sensitivity
- 76% > 0.5 NSE
- 4% < 0.0 NSE

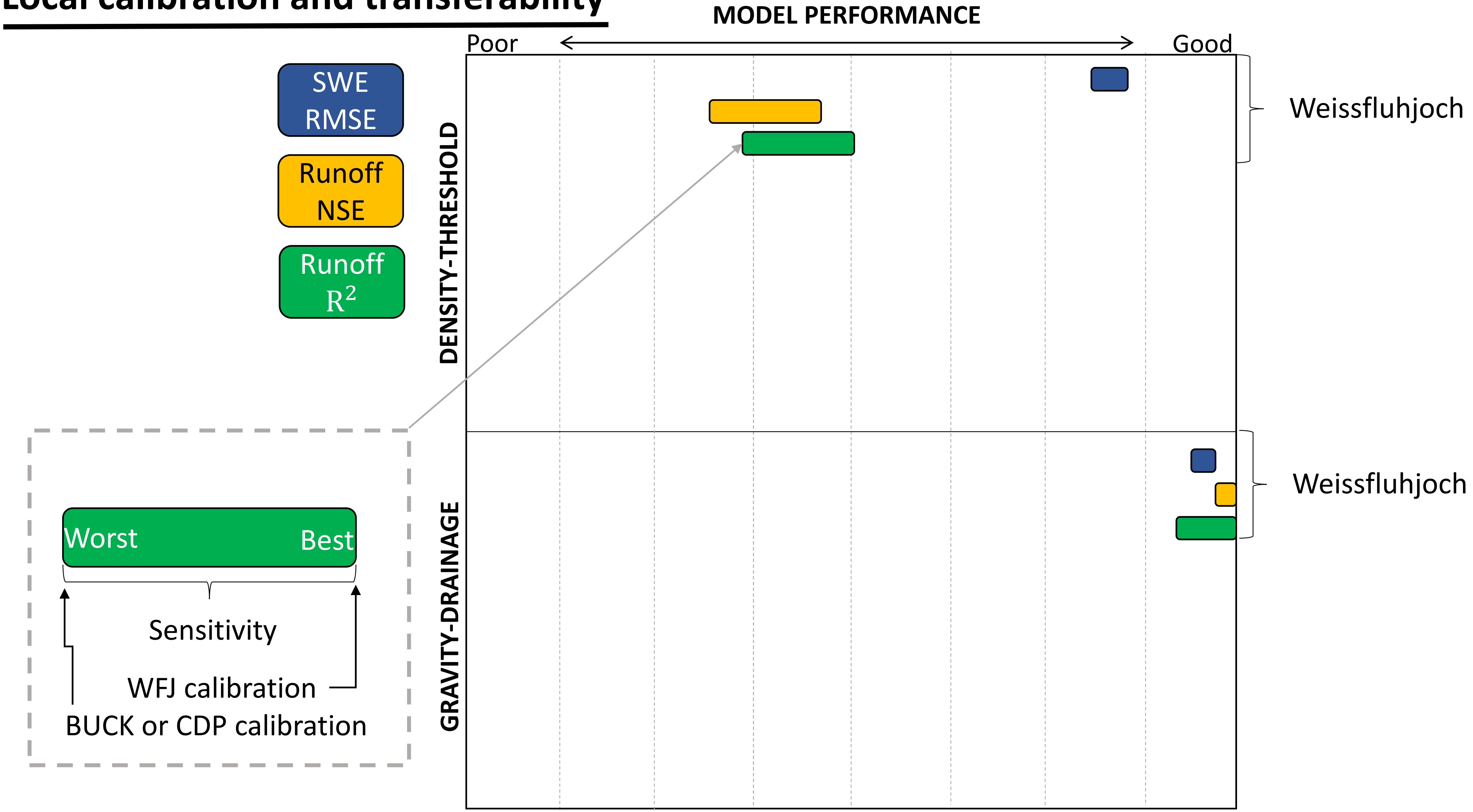
Local calibration and transferability



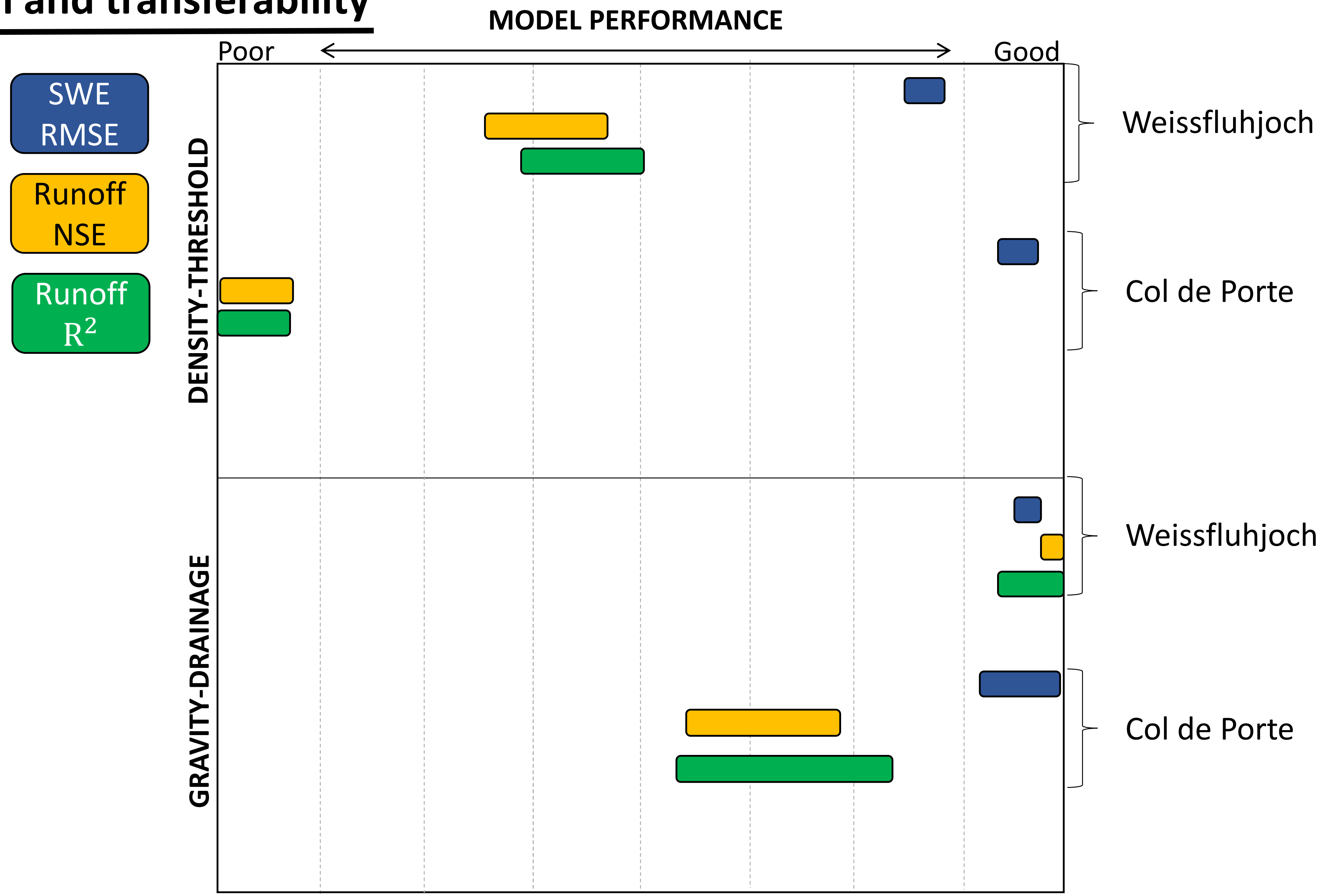
Local calibration and transferability



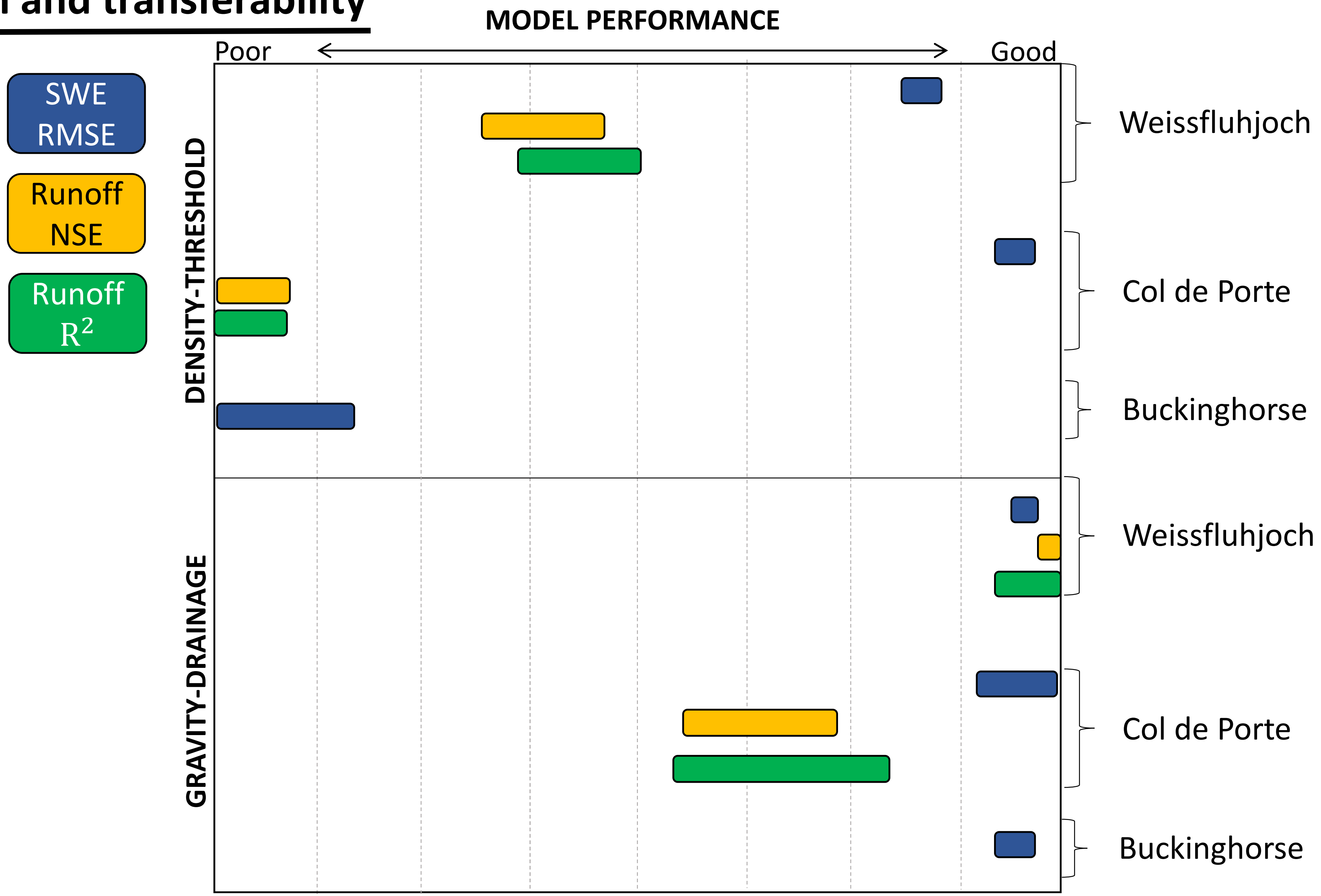
Local calibration and transferability



Local calibration and transferability



Local calibration and transferability



Study conclusions

- Percolation in accordance to a physically-motivated percolation routine outperforms the parameterized routine
- The physically-motivated percolation scheme displayed reduced parameter sensitivity
- Transferability in this experiment is indicative of process misrepresentation and model errors
- Transferability in this experiment is severely compromised when moving the parameterized routine to extreme climates

Lessons learned

- Hardcoded and "black-box" modeling decisions make errors in models difficult to attribute
- Models developed for a particular climate may not always be applicable in a different climate or period with climate change ("shantytown syndrome")
- Tradeoffs between model complexity and utility should be considered in the development process.

Thank you

Jessica Lundquist, Department of Civil and Environmental Engineering, University of Washington

Glen Liston, Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University

Bart Nijssen, Department of Civil and Environmental Engineering, University of Washington

Valle Scholarship

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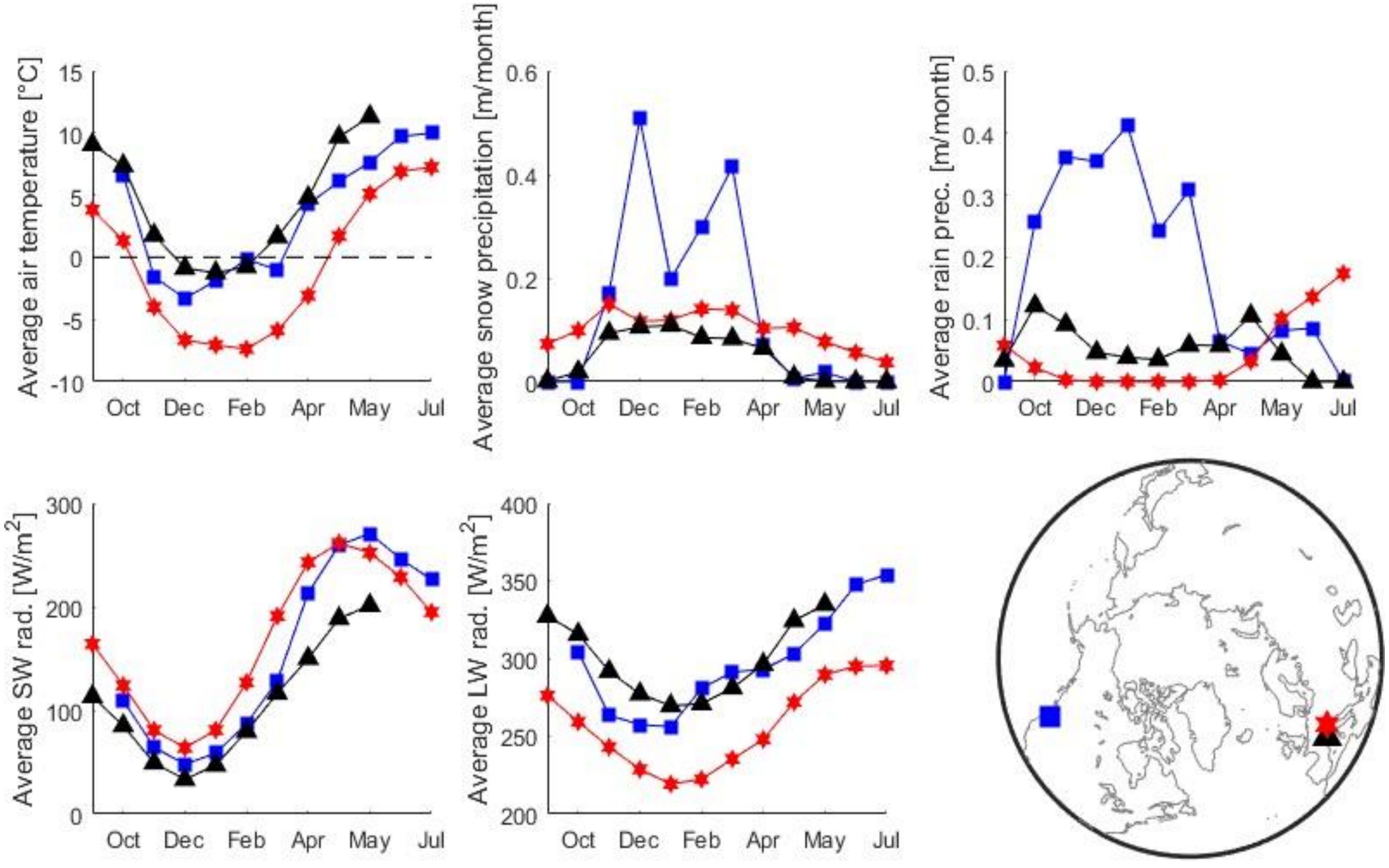
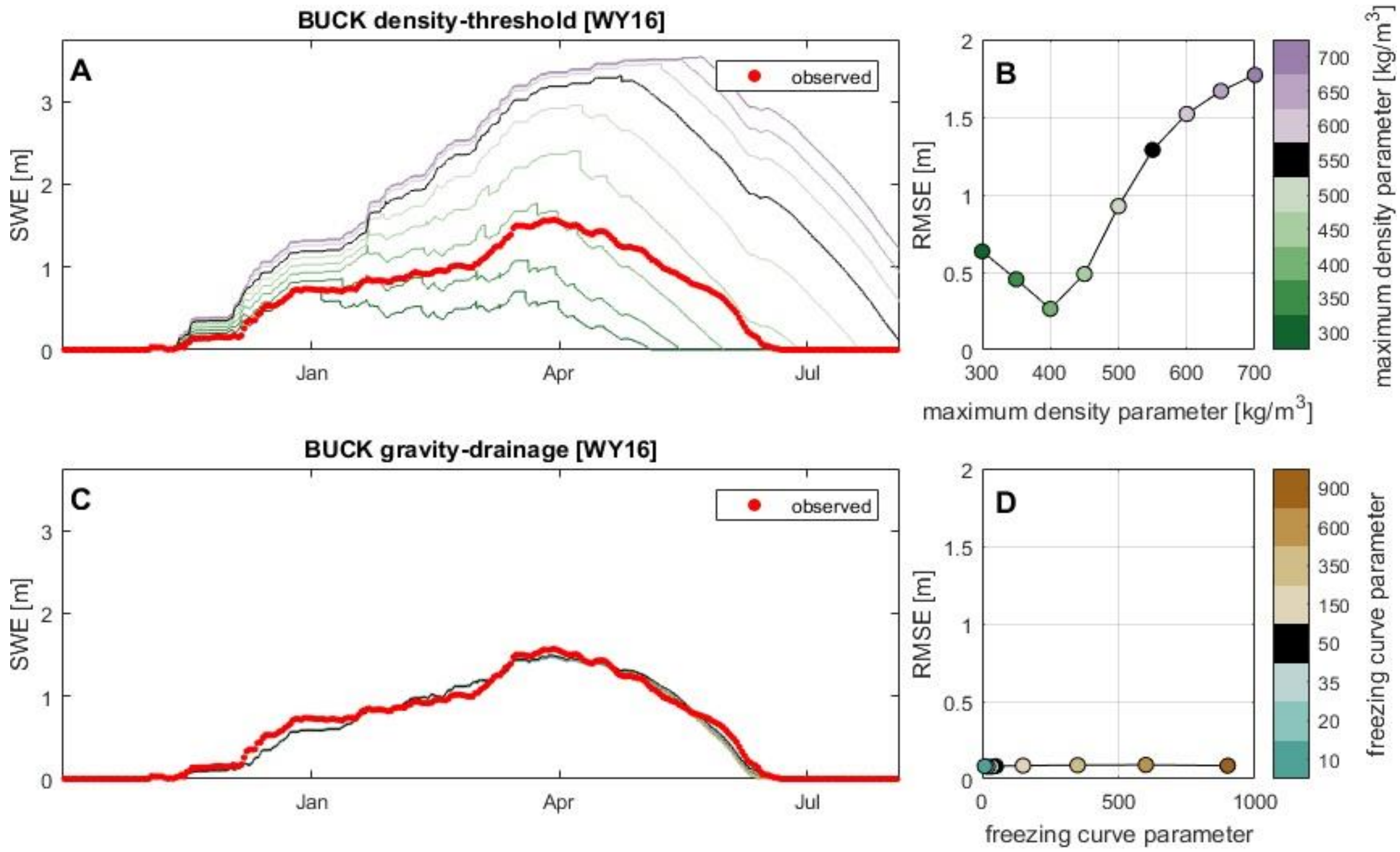
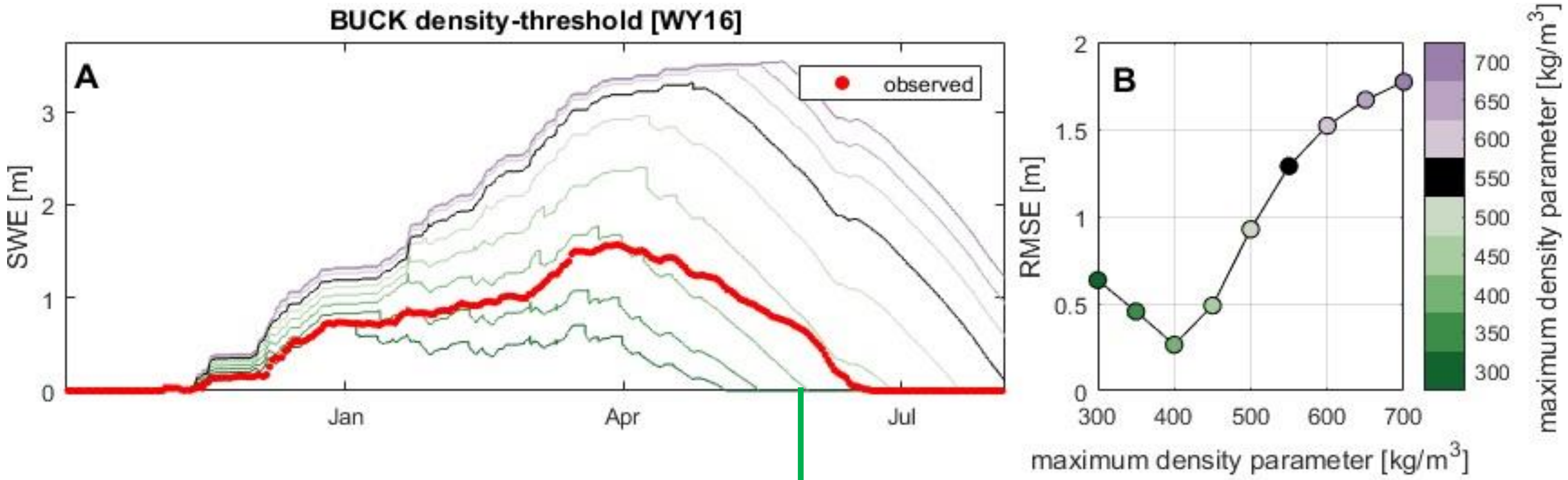
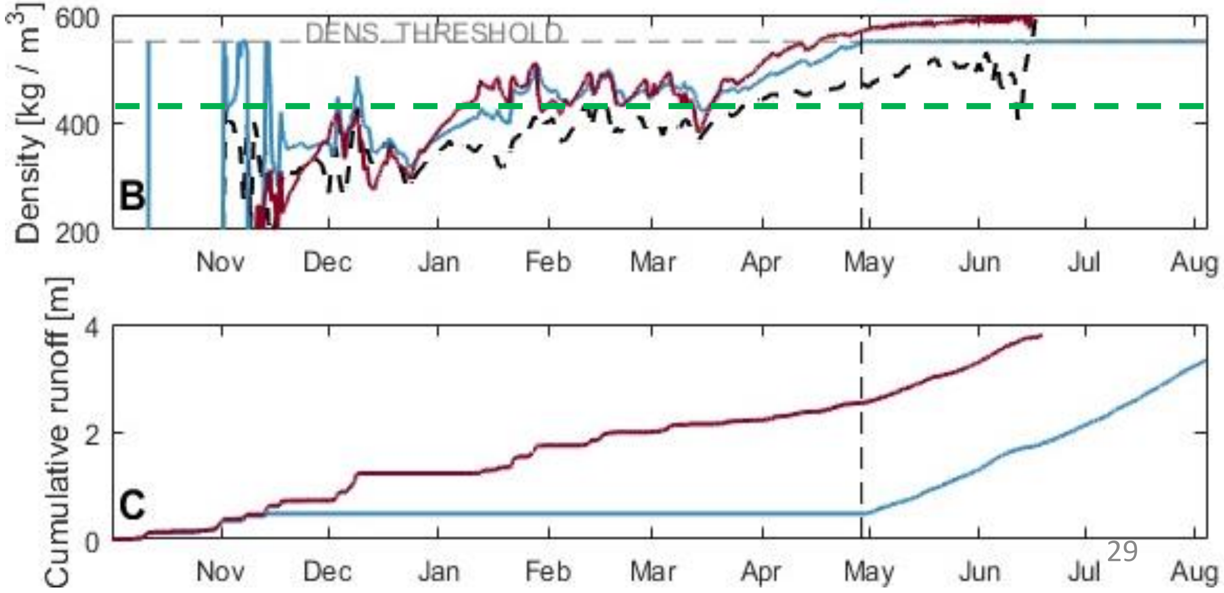
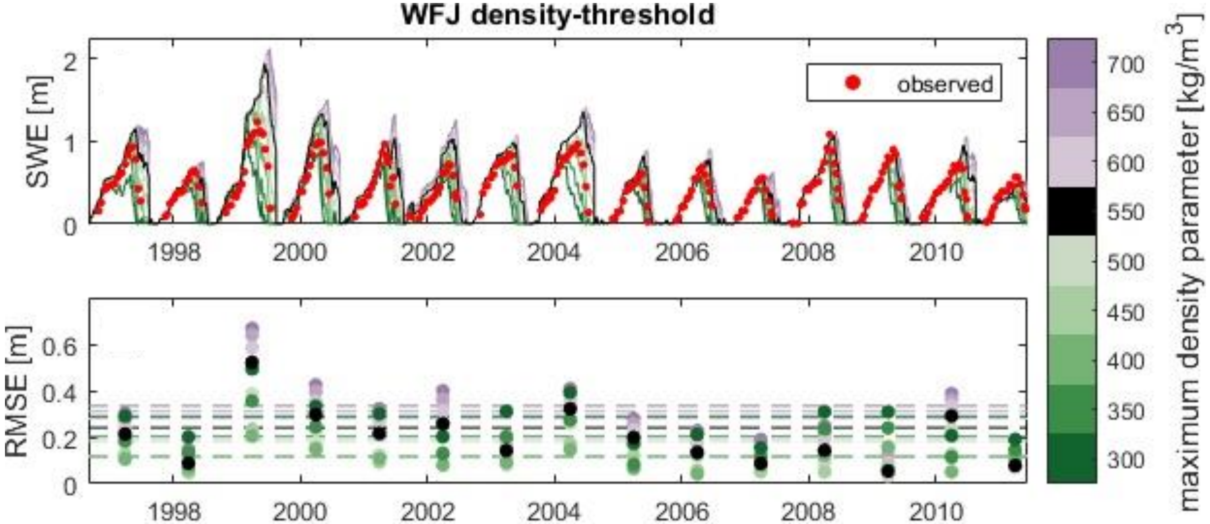
NASA

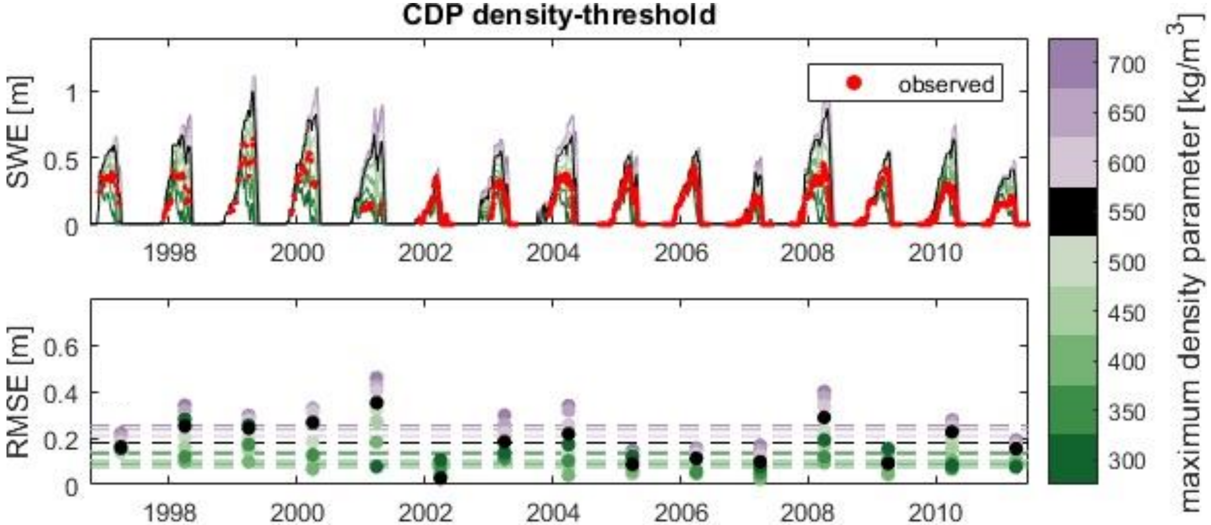

Average air temperature [°C]
15
10
5
0
-5
-10
Oct
Dec
Feb
Apr
May
Jul
Average snow precipitation [m/month]
0.6
0.4
0.2
0
Average rain prec. [m/month]
0.5
0.4
0.3
0.2
0.1
0
Average SW rad. [W/m2]
300
200
100
0
Average LW rad. [W/m2]
400
350
300
250
200

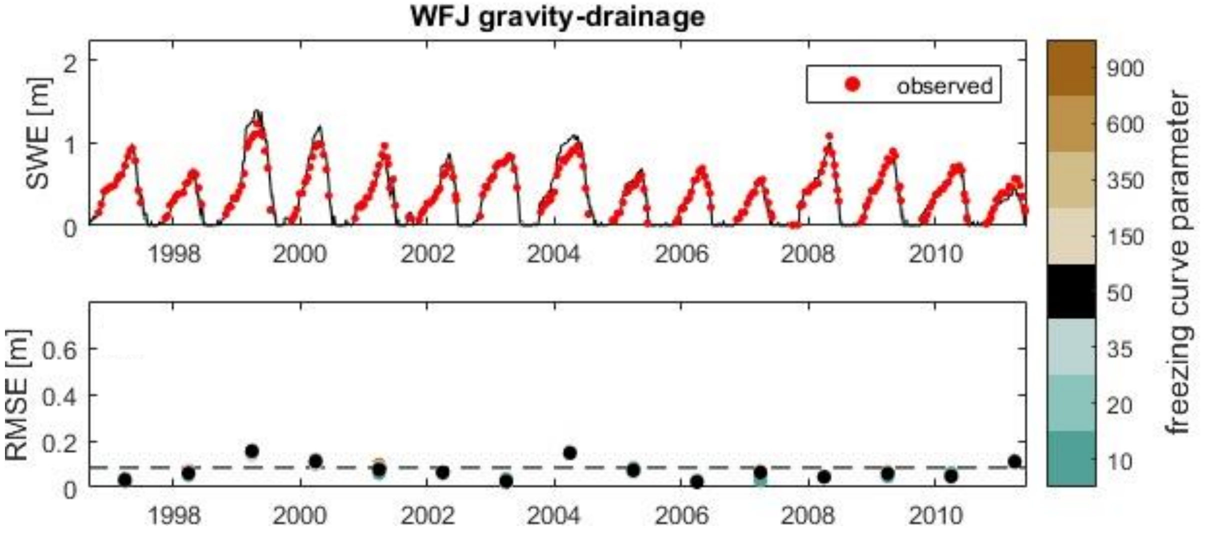

BUCK density-threshold [WY16]
A
observed
SWE [m]
0
1
2
3
Jan
Apr
Jul
B
RMSE [m]
0
0.5
1
1.5
2
300
400
500
600
700
maximum density parameter [kg/m^3]
700
650
600
550
500
450
400
350
300
maximum density parameter [kg/m^3]
BUCK gravity-drainage [WY16]
C
observed
SWE [m]
0
1
2
3
Jan
Apr
Jul
D
RMSE [m]
0
0.5
1
1.5
2
0
500
1000
freezing curve parameter
900
600
350
150
50
35
20
10
freezing curve parameter

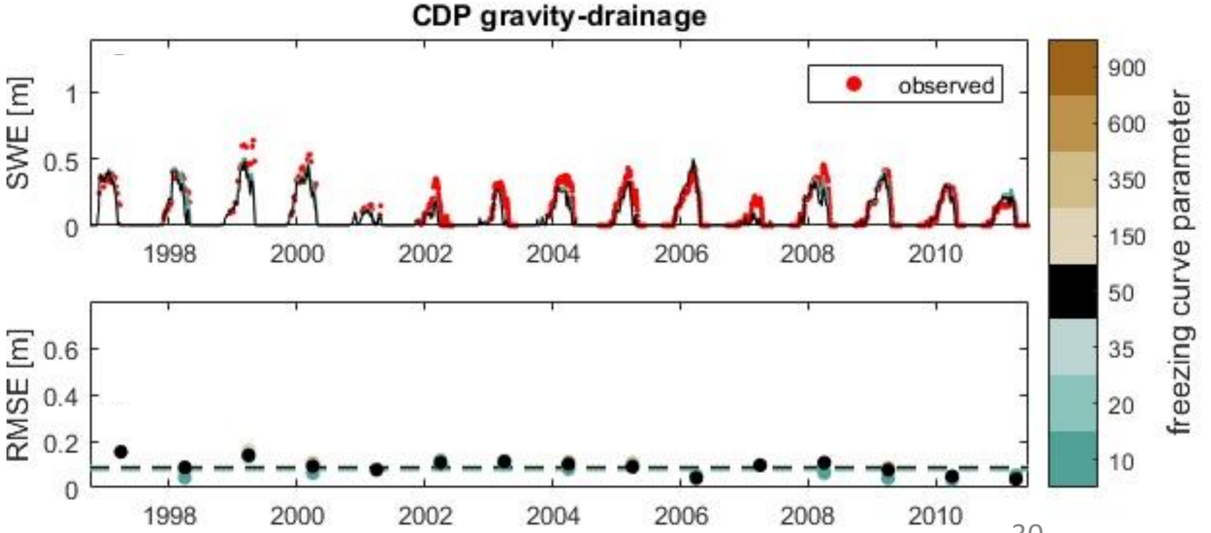

BUCK density-threshold [WY16]
A
observed
SWE [m]
0
1
2
3
Jan
Apr
Jul
B
RMSE [m]
0
0.5
1
1.5
2
300
400
500
600
700
maximum density parameter [kg/m3]
700
650
600
550
500
450
400
350
300
maximum density parameter [kg/m3]

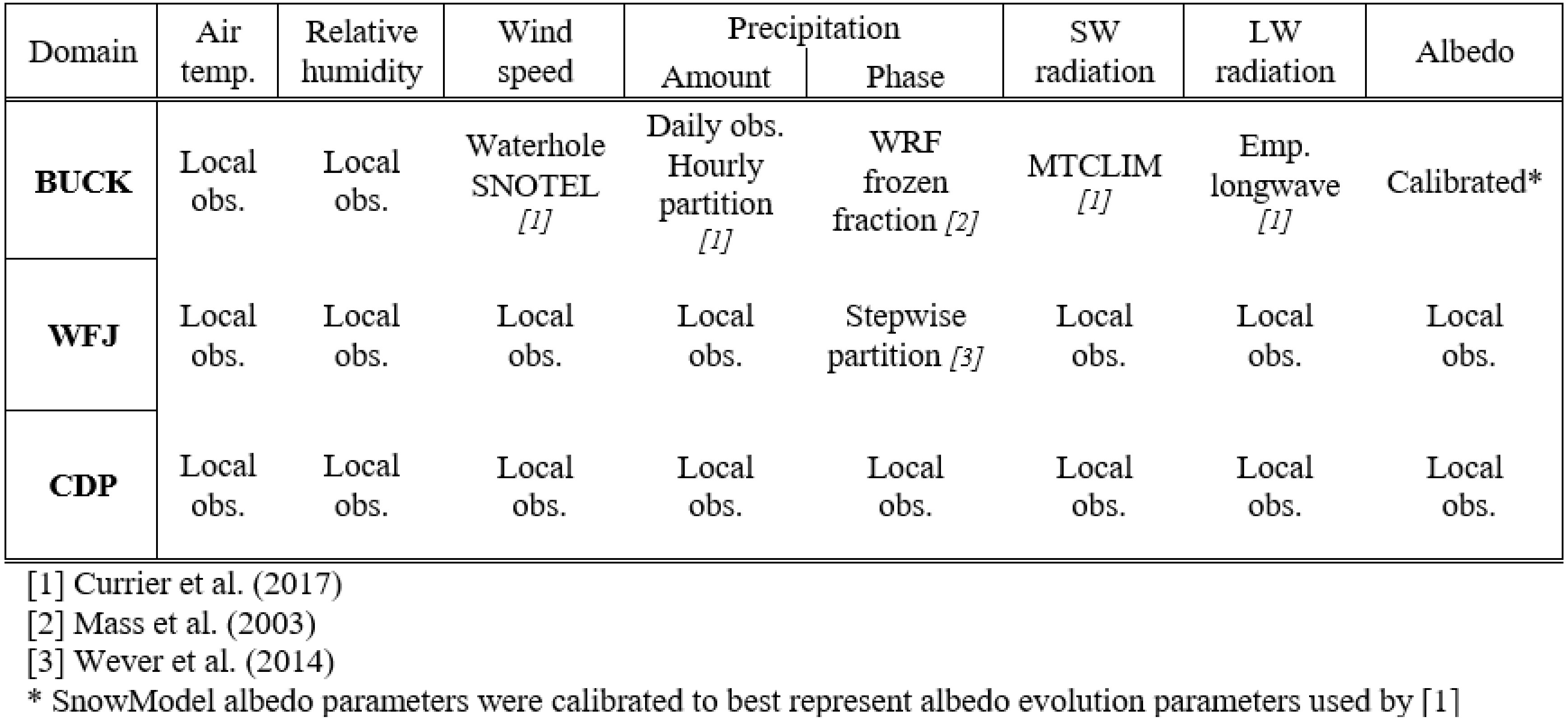

DENS. THRESHOLD
Density [kg / m3]
200
400
600
B
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Cumulative runoff [m]
0
2
4
C
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug


WFJ density-threshold


CDP density-threshold


WFJ gravity-drainage


CDP gravity-drainage



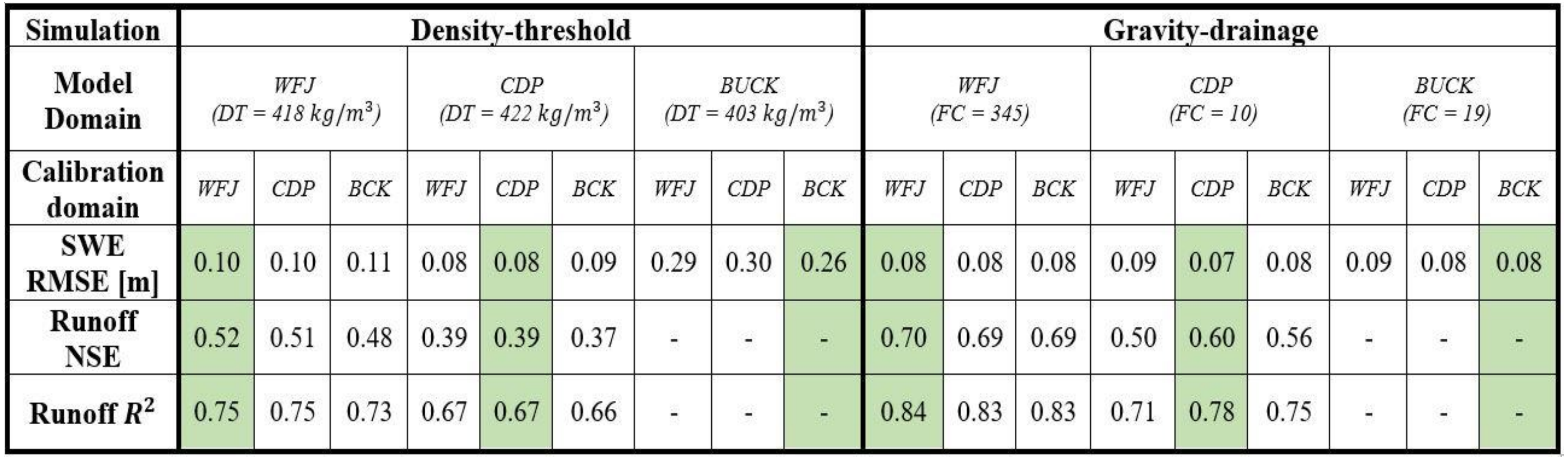
Domain	Air temp.	Relative humidity	Wind speed	Precipitation		SW radiation	LW radiation	Albedo
				Amount	Phase			
BUCK	Local obs.	Local obs.	Waterhole SNOTEL *[1]*	Daily obs. Hourly partition *[1]*	WRF frozen fraction *[2]*	MTCLIM *[1]*	Emp. longwave *[1]*	Calibrated*
WFJ	Local obs.	Local obs.	Local obs.	Local obs.	Stepwise partition *[3]*	Local obs.	Local obs.	Local obs.
CDP	Local obs.	Local obs.	Local obs.	Local obs.	Local obs.	Local obs.	Local obs.	Local obs.

[1] Currier et al. (2017)

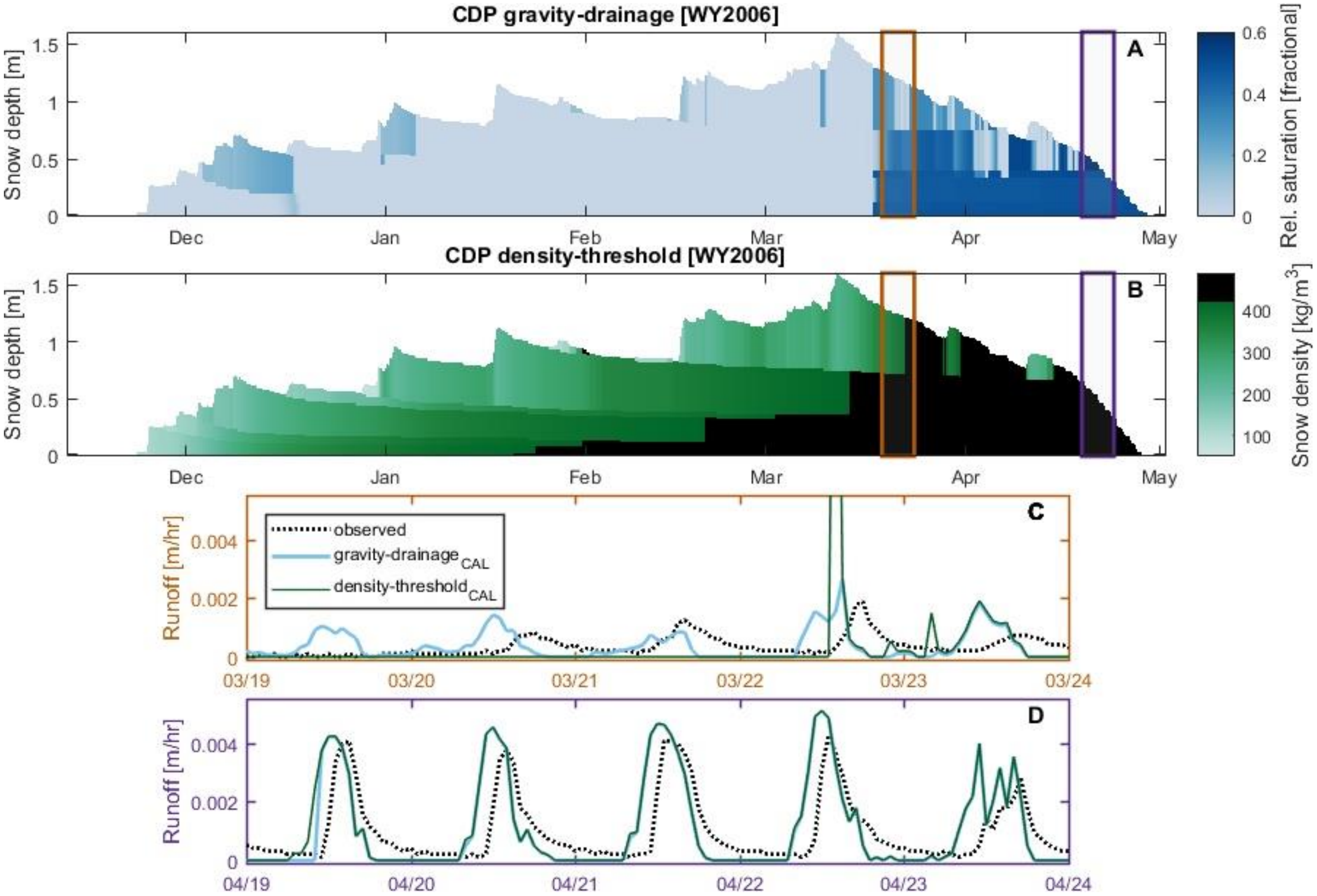
[2] Mass et al. (2003)

[3] Wever et al. (2014)

* SnowModel albedo parameters were calibrated to best represent albedo evolution parameters used by [1]

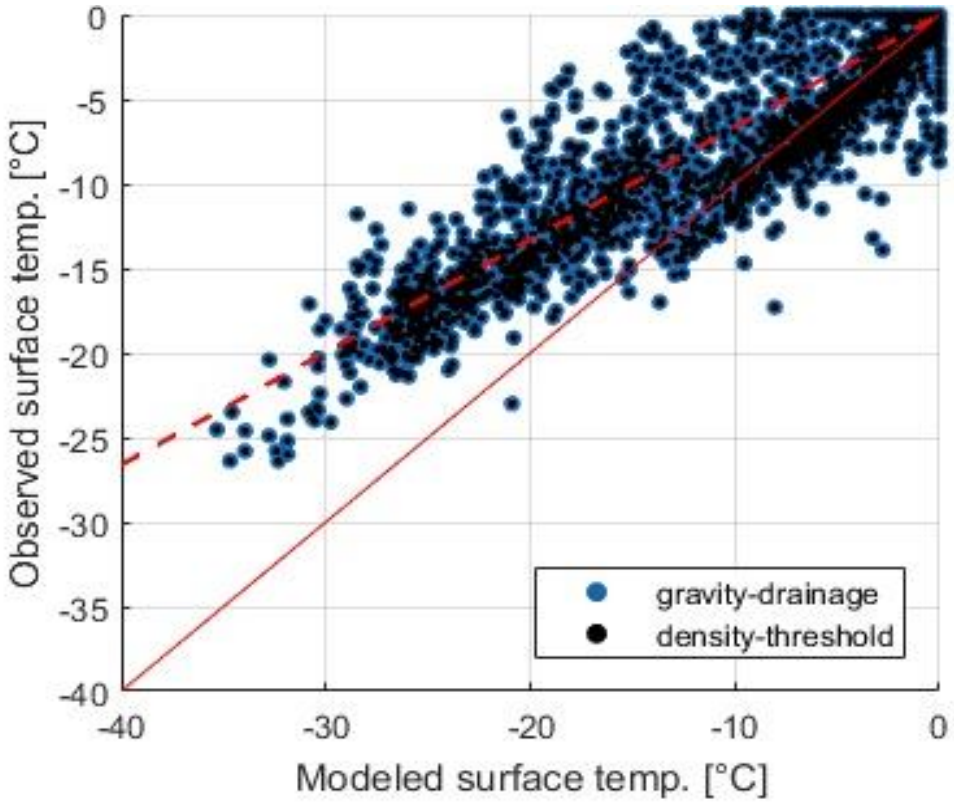


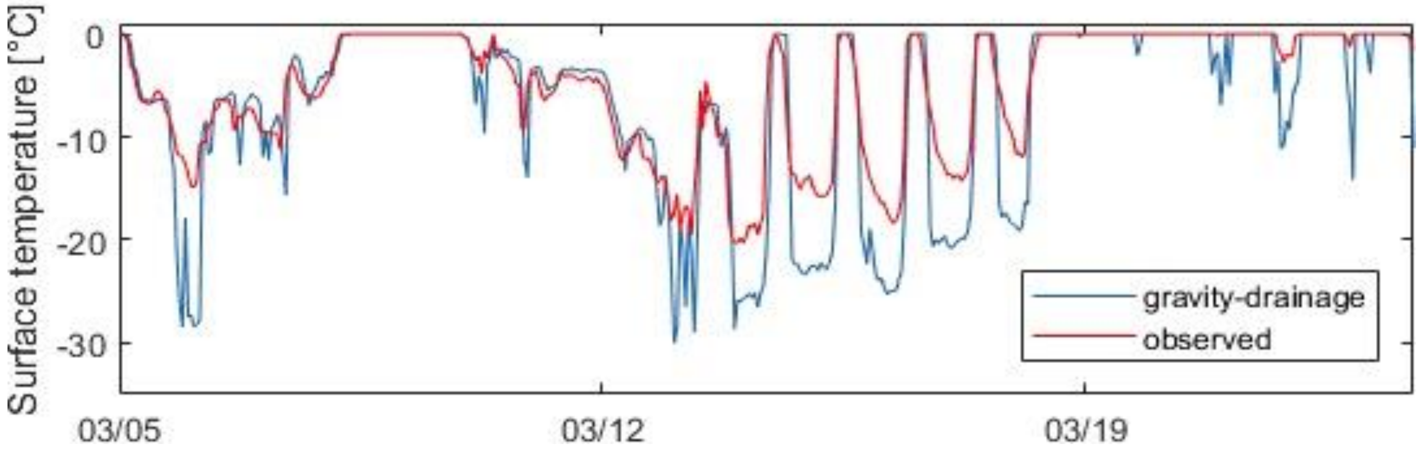
Simulation	**Density-threshold**									**Gravity-drainage**								
Model Domain	*WFJ (DT = 418 kg/m^3)*			*CDP (DT = 422 kg/m^3)*			*BUCK (DT = 403 kg/m^3)*			*WFJ (FC = 345)*			*CDP (FC = 10)*			*BUCK (FC = 19)*		
Calibration domain	*WFJ*	*CDP*	*BCK*	*WFJ*	*CDP*	*BCK*	*WFJ*	*CDP*	*BCK*	*WFJ*	*CDP*	*BCK*	*WFJ*	*CDP*	*BCK*	*WFJ*	*CDP*	*BCK*
SWE RMSE [m]	0.10	0.10	0.11	0.08	0.08	0.09	0.29	0.30	0.26	0.08	0.08	0.08	0.09	0.07	0.08	0.09	0.08	0.08
Runoff NSE	0.52	0.51	0.48	0.39	0.39	0.37	-	-	-	0.70	0.69	0.69	0.50	0.60	0.56	-	-	-
Runoff R^2	0.75	0.75	0.73	0.67	0.67	0.66	-	-	-	0.84	0.83	0.83	0.71	0.78	0.75	-	-	-

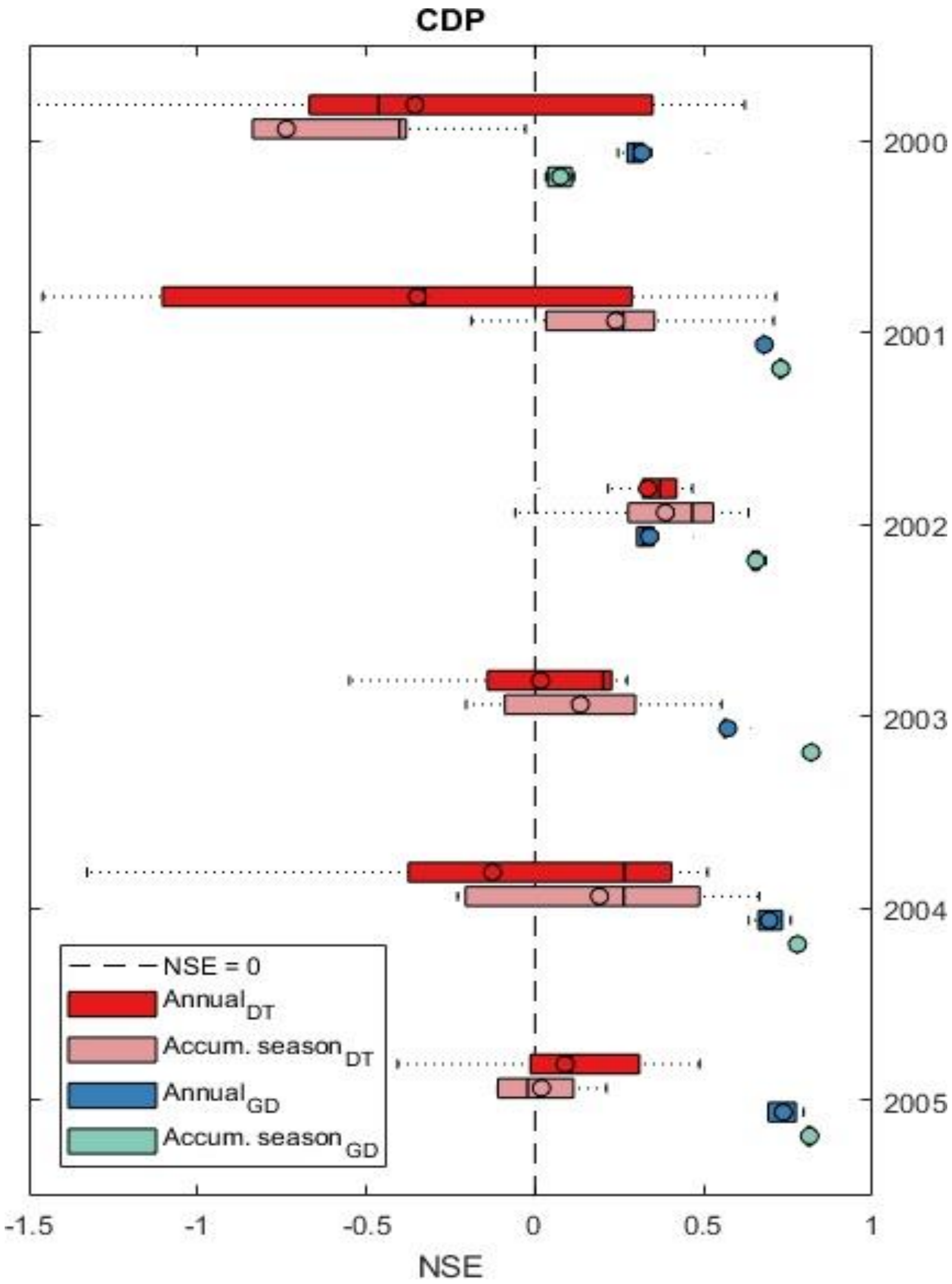


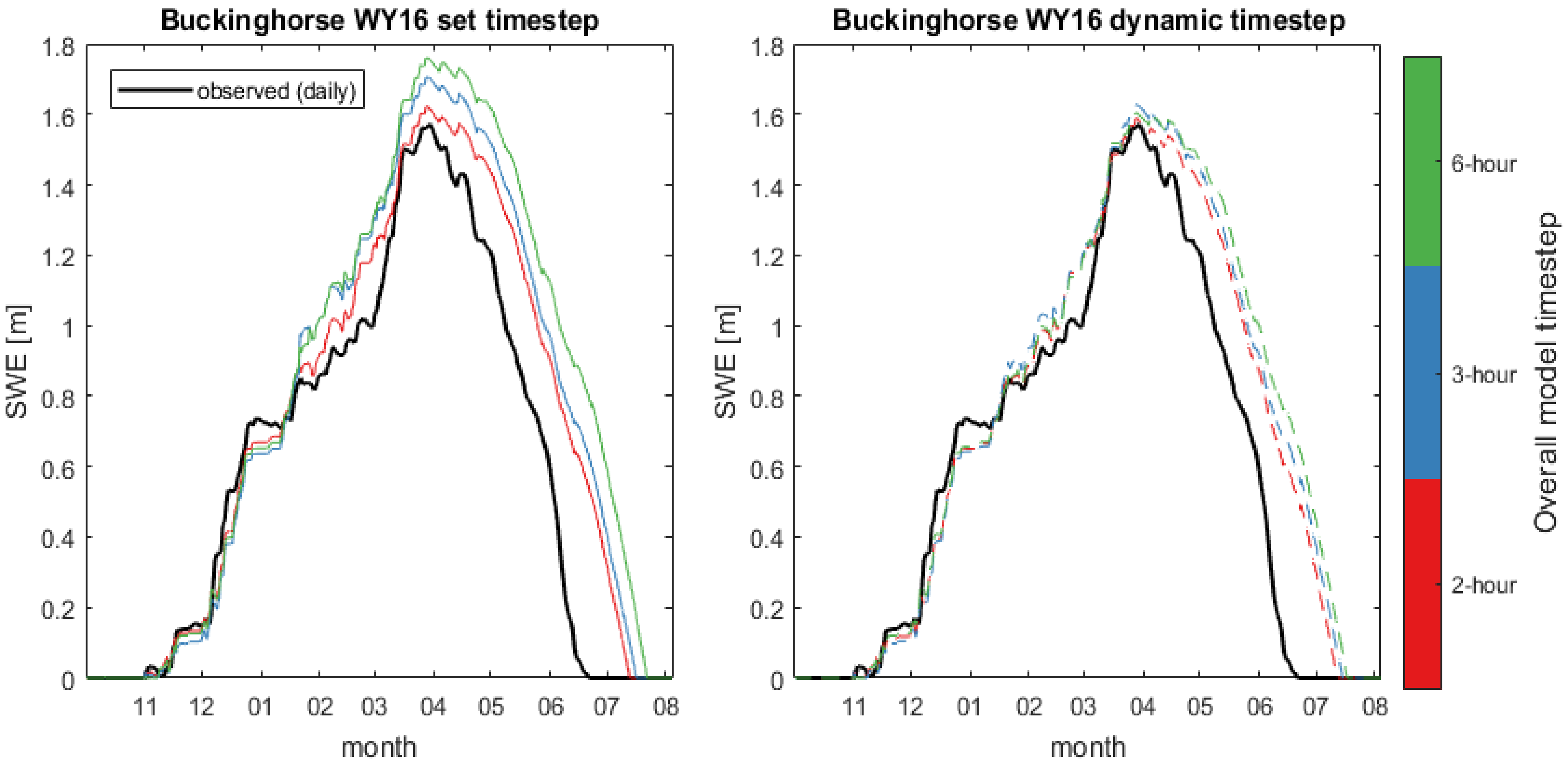
CDP gravity-drainage [WY2006]

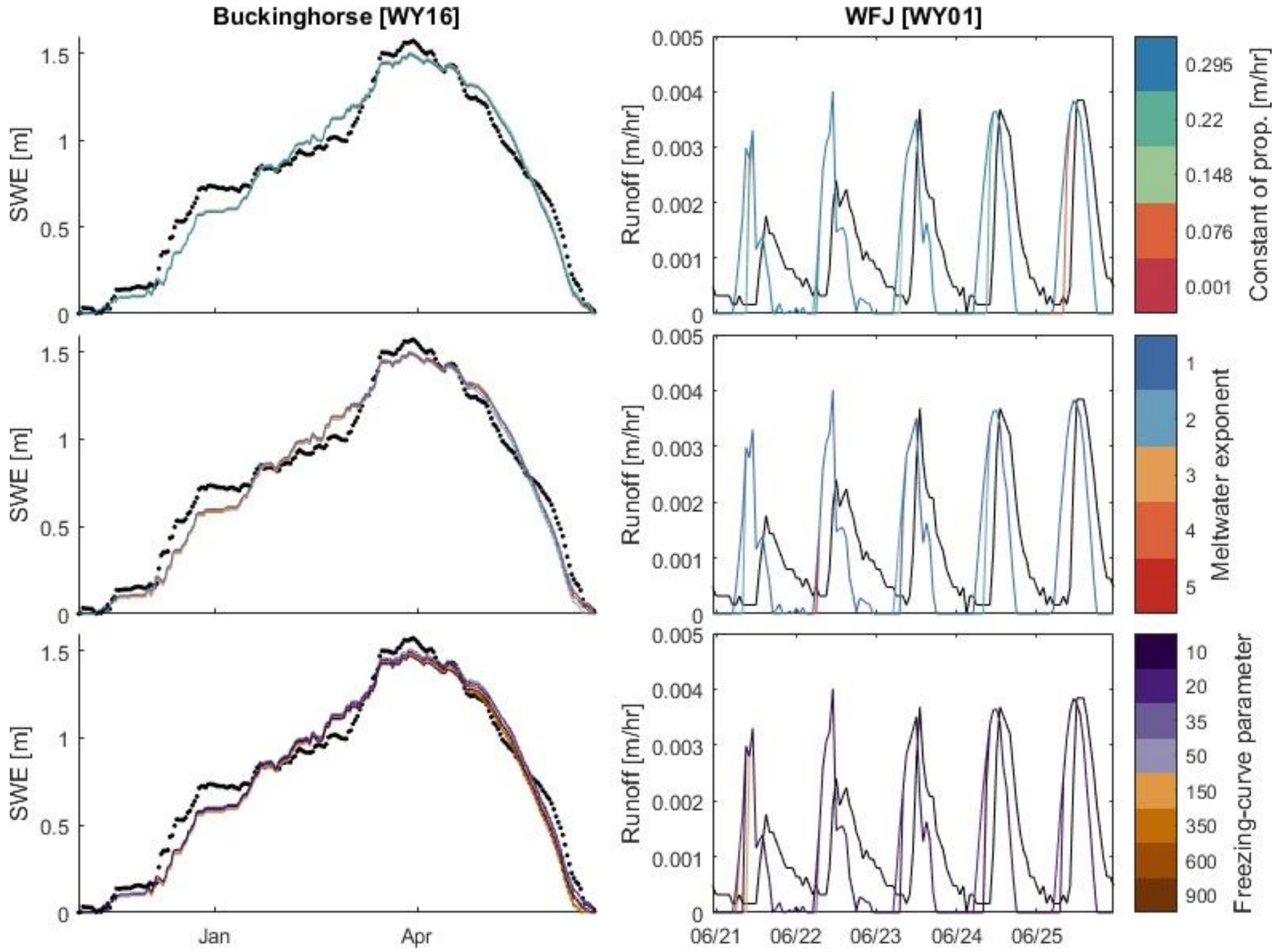
CDP density-threshold [WY2006]


Observed surface temp. [°C]
0
-5
-10
-15
-20
-25
-30
-35
-40
Modeled surface temp. [°C]
-40
-30
-20
-10
0
● gravity-drainage
● density-threshold


Surface temperature [°C]
0
-10
-20
-30
03/05
03/12
03/19
gravity-drainage
observed


CDP
2000
2001
2002
2003
2004
2005
NSE = 0
Annual$_{DT}$
Accum. season$_{DT}$
Annual$_{GD}$
Accum. season$_{GD}$
-1.5
-1
-0.5
0
0.5
1
NSE

Buckinghorse WY16 set timestep
Buckinghorse WY16 dynamic timestep
observed (daily)
SWE [m]
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
11
12
01
02
03
04
05
06
07
08
month
6-hour
3-hour
2-hour
Overall model timestep


Buckinghorse [WY16]
WFJ [WY01]
SWE [m]
0
0.5
1
1.5
Jan
Apr
Runoff [m/hr]
0
0.001
0.002
0.003
0.004
0.005
06/21
06/22
06/23
06/24
06/25
Constant of prop. [m/hr]
0.295
0.22
0.148
0.076
0.001
Meltwater exponent
1
2
3
4
5
Freezing-curve parameter
10
20
35
50
150
350
600
900