Progress report on CALMO - stage 2

Pavel Khain, Itzhak Carmona (IMS)

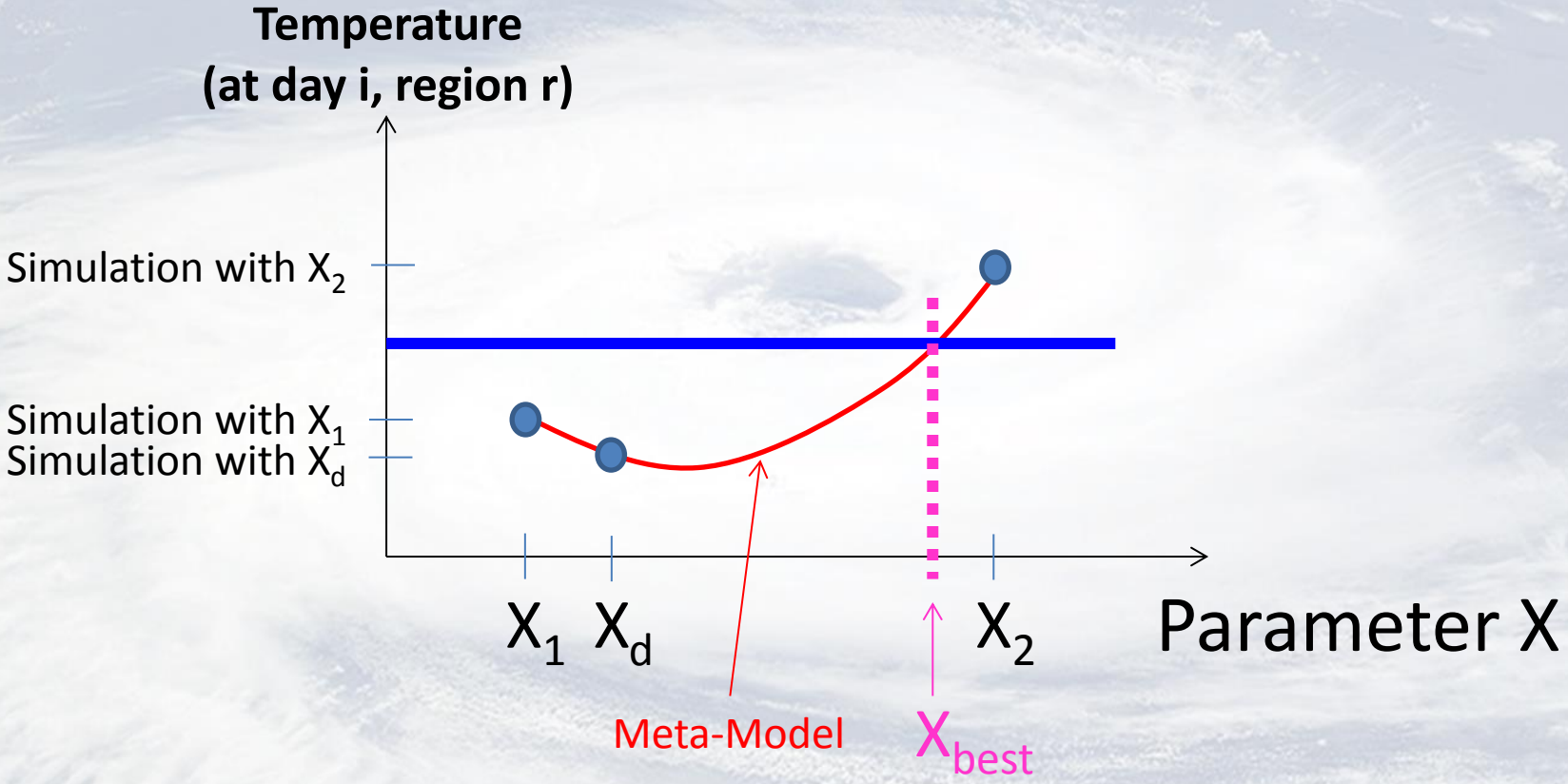
Antigoni Voudouri - head of the project, Euripides Avgoustoglou (HNMS)

Jean-Marie Bettems (MeteoSwiss)

Federico Grazzini (ARPA-SIMC)

COSMO General Meeting, Offenbach, September 2016

Reminder: Meta-Model - what is it?



Meta-Model (fit) at 3-dimensional parameters space:

$$F_{i,r} \cong F^d_{i,r} + c_{i,r} + a^{(1)}_{i,r} x_1 + B^{(1,1)}_{i,r} x_1^2 + a^{(2)}_{i,r} x_2 + B^{(2,2)}_{i,r} x_2^2 + a^{(3)}_{i,r} x_3 + B^{(3,3)}_{i,r} x_3^2 +$$
$$+ B^{(1,2)}_{i,r} x_1 x_2 + B^{(1,3)}_{i,r} x_1 x_3 + B^{(2,3)}_{i,r} x_2 x_3$$

field F at day i and region r

Outline

1. **Overview: from CALMO-stage1 to CALMO-stage2**
2. **Adaptations to the Meta-Model**
   - Option not to average Tmax/Tmin over regions
   - Meta-Model predicts profiles characteristics
   - Defining new regions
   - Performance scores
     - RMSE-type score
     - COSI-type score
   - Logarithmic transformation for some of the parameters
   - Convergence to the optimal parameters combination
3. **Calibration results**
4. **Summary**

Overview: from CALMO-stage1 to CALMO-stage2

- Increased resolution from 7km to 2.2km.
- Increased domain size of the simulations.
- Increased verification area to include also north of Italy.
- Added soundings profiles for parameters calibration.
- Increased simulations period (from 40 days of 2008 to entire year of 2013).
- Increased number of calibrated parameters (from 3 to 6):

	Min	Default	Max	Constrain
rlam_heat	0.1	1	2	0.2
tkhmin	0.1	0.4	1	0.7
tur_len	100	150	1000	316
entr_sc	0.05e-3	0.3e-3	2e-3	0.795e-3
csoil	0	1	2	0.5
v0snow	10	20	30	15

Outline

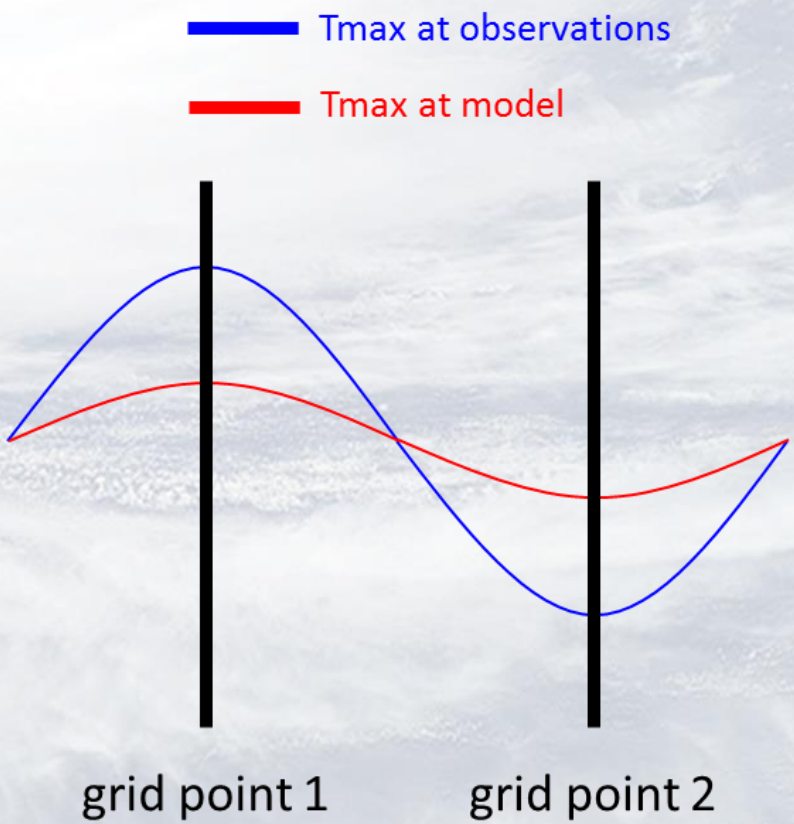
1. **Overview: from CALMO-stage1 to CALMO-stage2**
2. **Adaptations to the Meta-Model**
   - Option not to average Tmax/Tmin over regions
   - Meta-Model predicts profiles characteristics
   - Defining new regions
   - Performance scores
     - RMSE-type score
     - COSI-type score
   - Logarithmic transformation for some of the parameters
   - Convergence to the optimal parameters combination
3. **Calibration results**
4. **Summary**

Option not to average Tmax/Tmin over regions

Precipitation: region averaging reduces the noise

Tmax/Tmin: averaging → loss of information.

Example:
Tmax errors at two different grid points can yield no error on average:



Outline

1. **Overview: from CALMO-stage1 to CALMO-stage2**
2. **Adaptations to the Meta-Model**
   - Option not to average Tmax/Tmin over regions
   - Meta-Model predicts profiles characteristics
   - Defining new regions
   - Performance scores
     - RMSE-type score
     - COSI-type score
   - Logarithmic transformation for some of the parameters
   - Convergence to the optimal parameters combination
3. **Calibration results**
4. **Summary**

Meta-Model predicts profiles characteristics

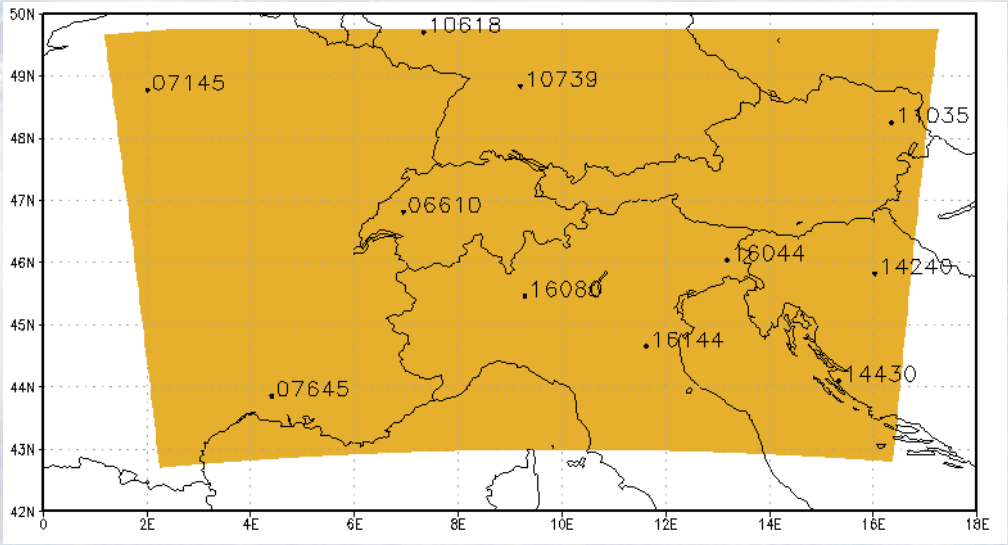
CALMO-stage1:

- Daily maximum 2m temperature
- Daily minimum 2m temperature
- 24h accumulated precipitation

CALMO-stage2 - added:

- Convective available potential energy
- Convective inhibition
- Total column water vapor
- Vector wind shear between 500mb - 700mb, 700mb - 850mb, 850mb - 1000mb
- Temperatures at 500mb, 700mb and 850mb
- Relative humidity at 500mb, 700mb and 850mb
- E-W and S-N wind components at 500mb, 700mb and 850mb

11 available soundings at the CALMO-2 domain :



Outline

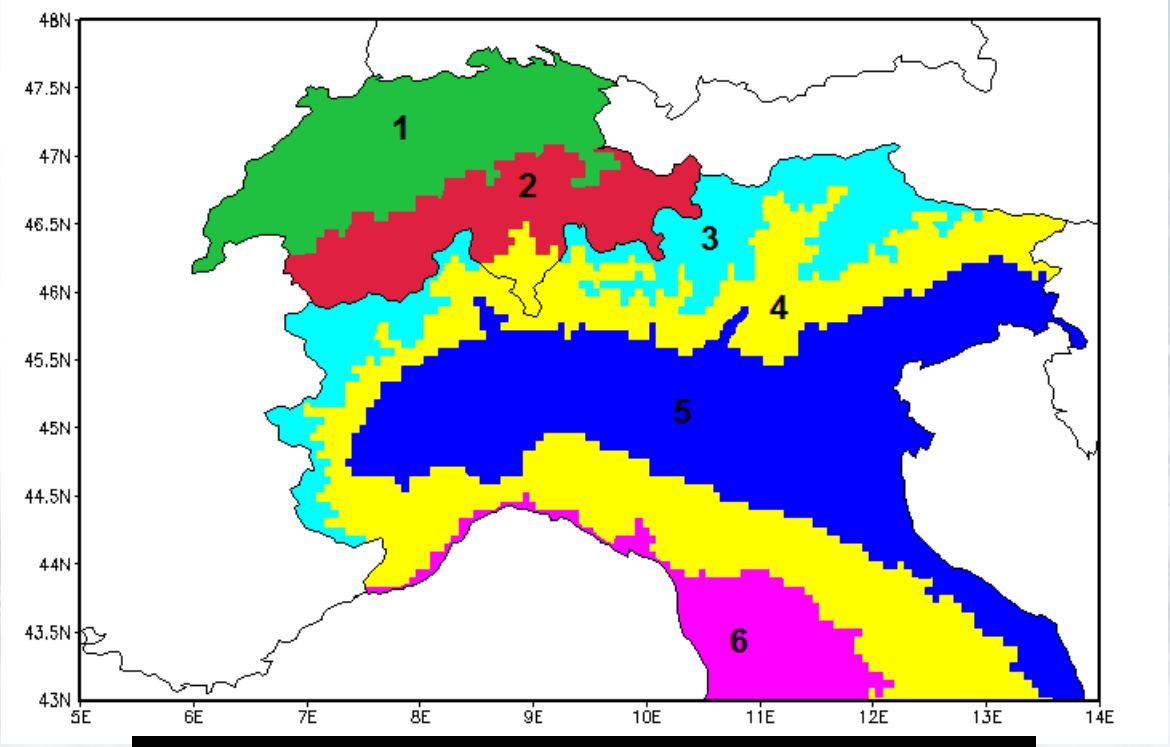
1. **Overview: from CALMO-stage1 to CALMO-stage2**
2. **Adaptations to the Meta-Model**
   - Option not to average Tmax/Tmin over regions
   - Meta-Model predicts profiles characteristics
   - Defining new regions
   - Performance scores
     - RMSE-type score
     - COSI-type score
   - Logarithmic transformation for some of the parameters
   - Convergence to the optimal parameters combination
3. **Calibration results**
4. **Summary**

Defining new regions

CALMO-stage1: Switzerland only

CALMO-stage2 –

added North Italy:



1: Swiss plateau (300m<h<1500m)
2: Swiss Alps (1500m<h)
3: Italian Alps (1500m<h)
4: Italian hills and Ticino (300m<h<1500m)
5: Po Valley (h<300m)
6: Italian north-west coast (mainly h<300m)

Outline

1. **Overview: from CALMO-stage1 to CALMO-stage2**
2. **Adaptations to the Meta-Model**
   - Option not to average Tmax/Tmin over regions
   - Meta-Model predicts profiles characteristics
   - Defining new regions
   - Performance scores
     - RMSE-type score
     - COSI-type score
   - Logarithmic transformation for some of the parameters
   - Convergence to the optimal parameters combination
3. **Calibration results**
4. **Summary**

Performance scores - reminder

For p=1:10000 parameter combinations

Use the MM to get COSMO fields $F_{i,r}$ (for all days i and regions r)

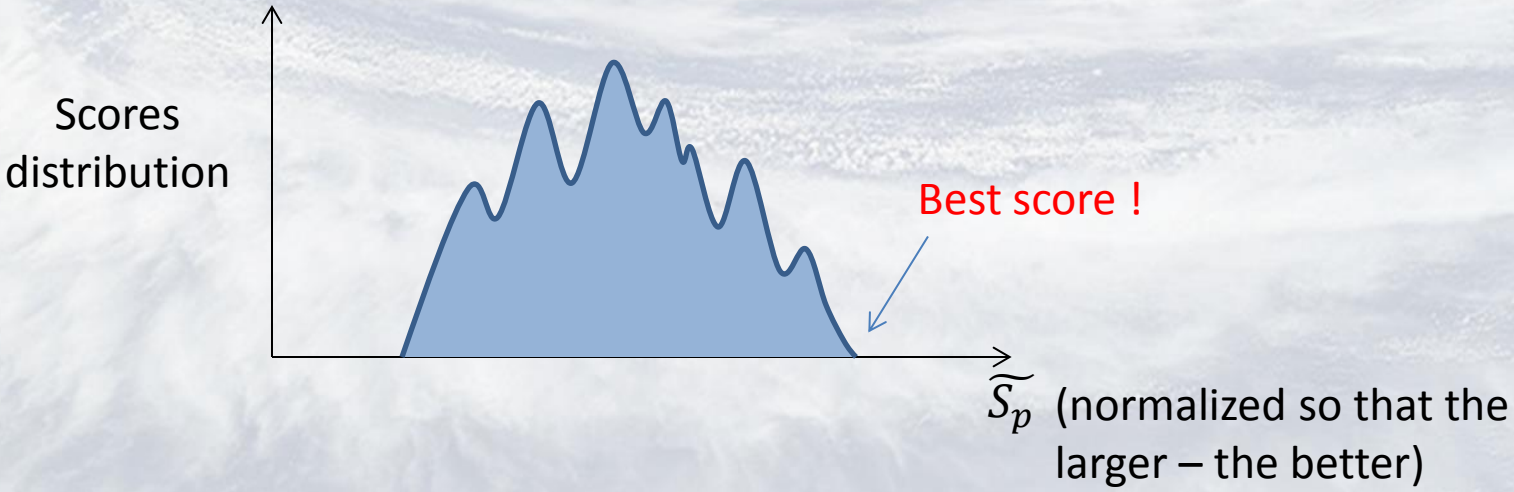
Collect observation fields $O_{i,r}$ (for all days i and regions r)

Calculate the score S_p (how good were the forecasts during the time period over the entire area)

End

Among 10000 S_p , find the best S_p

Find which parameter combination (p) corresponds to that S_p



Outline

1. **Overview: from CALMO-stage1 to CALMO-stage2**
2. **Adaptations to the Meta-Model**
   - Option not to average Tmax/Tmin over regions
   - Meta-Model predicts profiles characteristics
   - Defining new regions
   - Performance scores
     - RMSE-type score
     - COSI-type score
   - Logarithmic transformation for some of the parameters
   - Convergence to the optimal parameters combination
3. **Calibration results**
4. **Summary**

Performance scores - RMSE-type

$$S_p = \left\{ \frac{1}{12\sum_{\Psi=1}^{21}\omega_\Psi} \sum_{\Psi=1}^{21}\omega_\Psi \sum_{mon=1}^{12} W_{\Psi,mon} \frac{1}{N_{\Psi days,mon} N_{\Psi regs,mon}} \sum_{\Psi regs} \left[\frac{\sum_{\Psi days} \left(F_{\Psi,p,d,r,mon} - O_{\Psi,d,r,mon} \right)^2}{\sigma^2_{\Psi,r,mon}} \right] \right\}^{1/2}$$

Observations variability :

$$\sigma_{\Psi,r,mon} = \sqrt{\frac{1}{N_{\Psi days,mon}} \sum_{\Psi days} \left(O_{\Psi,d,r,mon} - \overline{O}_{\Psi,d,r,mon} \right)^2}$$

Normalization weights :

$$W_{\Psi,mon} = \frac{1}{N_p} \sum_{p=1}^{N_p} \frac{1}{N_{\Psi days,mon} N_{\Psi regs,mon}} \sum_{\Psi regs} \left[\frac{\sum_{\Psi days} \left(F_{\Psi,p,d,r,mon} - O_{\Psi,d,r,mon} \right)^2}{\sigma^2_{\Psi,r,mon}} \right]$$

User defined weights :

$\omega_{T\max} = 1$, $\omega_{T\min} = 1$, $\omega_{\Pr} = 1$, $\omega_{CAPE} = 0$, $\omega_{CIN} = 0$, $\omega_{TCWV} = 1$, $\omega_{WS1} = 0.33$, $\omega_{WS2} = 0.33$, $\omega_{WS3} = 0.33$,

$\omega_{T500} = 0.33$, $\omega_{T700} = 0.33$, $\omega_{T850} = 0.33$, $\omega_{RH500} = 0.33$, $\omega_{RH700} = 0.33$, $\omega_{RH850} = 0.33$, $\omega_{U500} = 0.2$,

$\omega_{U700} = 0.2$, $\omega_{U850} = 0.2$, $\omega_{V500} = 0.2$, $\omega_{V700} = 0.2$, $\omega_{V850} = 0.2$.

Outline

1. **Overview: from CALMO-stage1 to CALMO-stage2**
2. **Adaptations to the Meta-Model**
   - Option not to average Tmax/Tmin over regions
   - Meta-Model predicts profiles characteristics
   - Defining new regions
   - Performance scores
     - RMSE-type score
     - COSI-type score
   - Logarithmic transformation for some of the parameters
   - Convergence to the optimal parameters combination
3. **Calibration results**
4. **Summary**

Performance scores - COSI-type

(U.Damrath)

For parameter combination p :

$$COSI_p = \sum_{fields\ i} sk_{p,i}$$

For continuous fields:

$$sk_{p,i} = 1 - \frac{{rmse_{p,i}}^2}{{rmse_{pers,i}}^2}$$

$${rmse_{p,i}}^2 = \frac{\sum_r \sum_i \left[F_{p,i,r} - O_{i,r}\right]^2}{N_{regions} N_{days}}$$

$${rmse_{pers,i}}^2 = \frac{\sum_r \sum_i \left[O_{i,r} - O_{i-1,r}\right]^2}{N_{regions}(N_{days}-1)}$$

For categorical fields:

$$sk_{p,i} = \frac{\sum_{thresholds} \sum_{regions} ETS_{p,i,thr,r}}{N_{regs} \times N_{thresholds}}$$

$$ETS = \frac{a - a_{ch}}{a + b + c - a_{ch}} \qquad a_{ch} = \frac{(a+b)*(a+c)}{a+b+c+d}$$

ETS between: -1/3 to 1

Event forecasted	Event observed:	
	YES	NO
YES	**a**	**b**
NO	**c**	**d**

a = "hit" ; b = "false alarm“
c = "missed" ; d = “true negative"

Performance scores - COSI-type

$$S_p = \frac{1}{12\sum_{\Psi=1}^{18}\omega_\Psi}\left\{\sum_{\Psi\neq 3}\omega_\Psi\sum_{mon=1}^{12}\left[1-\frac{\sum_{\Psi regs}\sum_{\Psi days}\left(F_{\Psi,p,d,r,mon}-O_{\Psi,d,r,mon}\right)^2}{\sum_{\Psi regs}\sum_{\Psi days}\left(O_{\Psi,d-1,r,mon}-O_{\Psi,d,r,mon}\right)^2}\right]+\omega_3\frac{\sum_{mon=1}^{12}\sum_{\Psi regs}\sum_{\Psi thr}ETS_{p,r,mon,thr}}{N_{\Psi days,mon}N_{\Psi regs,mon}}\right\}$$

Region averaged precipitation amounts thresholds: 0.1,1,3,7.5,10mm per 24h

Reminder – RMSE type:

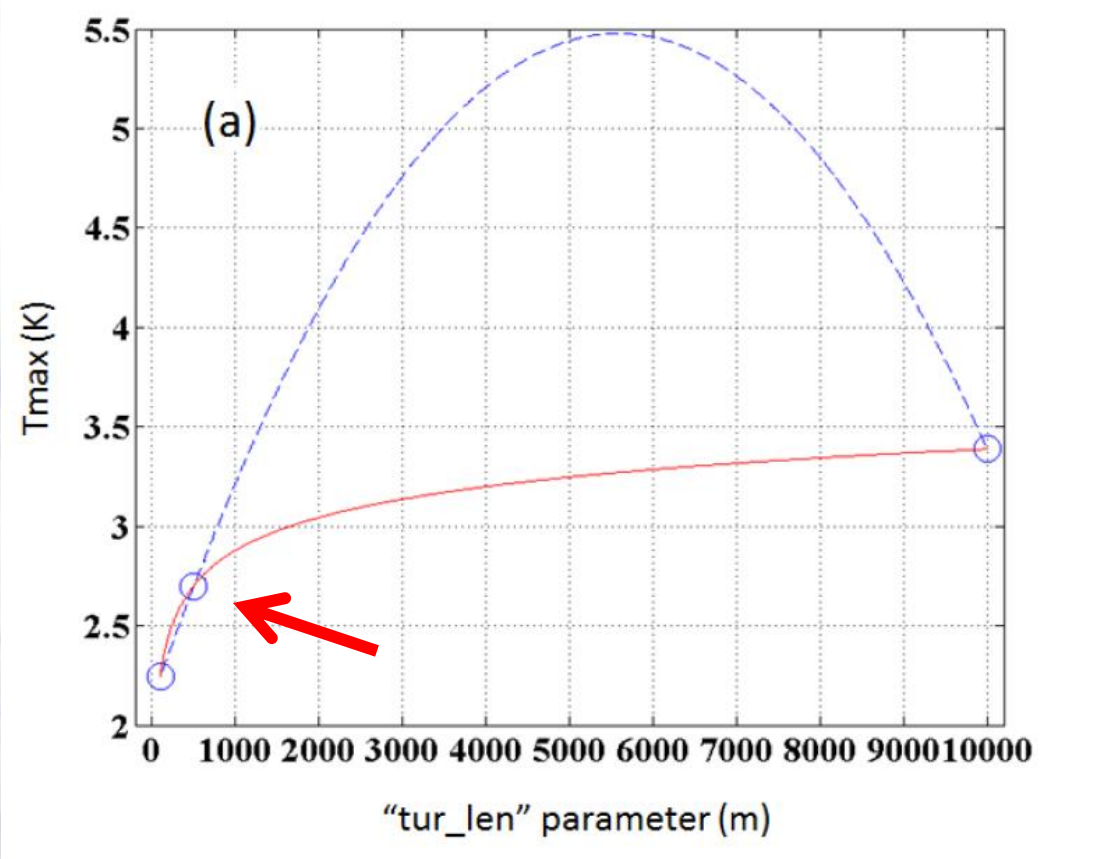
$$S_p = \left\{\frac{1}{12\sum_{\Psi=1}^{21}\omega_\Psi}\sum_{\Psi=1}^{21}\omega_\Psi\sum_{mon=1}^{12}\frac{1}{W_{\Psi,mon}N_{\Psi days,mon}N_{\Psi regs,mon}}\sum_{\Psi regs}\left[\frac{\sum_{\Psi days}\left(F_{\Psi,p,d,r,mon}-O_{\Psi,d,r,mon}\right)^2}{\sigma^2_{\Psi,r,mon}}\right]\right\}^{1/2}$$

Outline

1. **Overview: from CALMO-stage1 to CALMO-stage2**
2. **Adaptations to the Meta-Model**
   - Option not to average Tmax/Tmin over regions
   - Meta-Model predicts profiles characteristics
   - Defining new regions
   - Performance scores
     - RMSE-type score
     - COSI-type score
   - Logarithmic transformation for some of the parameters
   - Convergence to the optimal parameters combination
3. **Calibration results**
4. **Summary**

Logarithmic transformation for some of the parameters

Parabola interpolation is problematic when the default parameter value is located far away from the center:



Logarithmic transformation for some of the parameters

Recently we have developed a method to objectively transform these parameters to logarithmic space:

$x \to \hat{x} \equiv \log\left(\alpha \frac{x - x_{\min}}{x_{\max} - x_{\min}} + \beta\right)$. The demand for the transformed default value to be exactly at the center between the minimum and maximum values, i.e. $\hat{x}_d - \hat{x}_{\min} \overset{!}{=} \hat{x}_{\max} - \hat{x}_d$ defines α and β. Applying the procedure yielded $\alpha = 72, \beta = 0.25$, for tur_len, and $\alpha = 9500, \beta = 210$ for entr_sc.

Outline

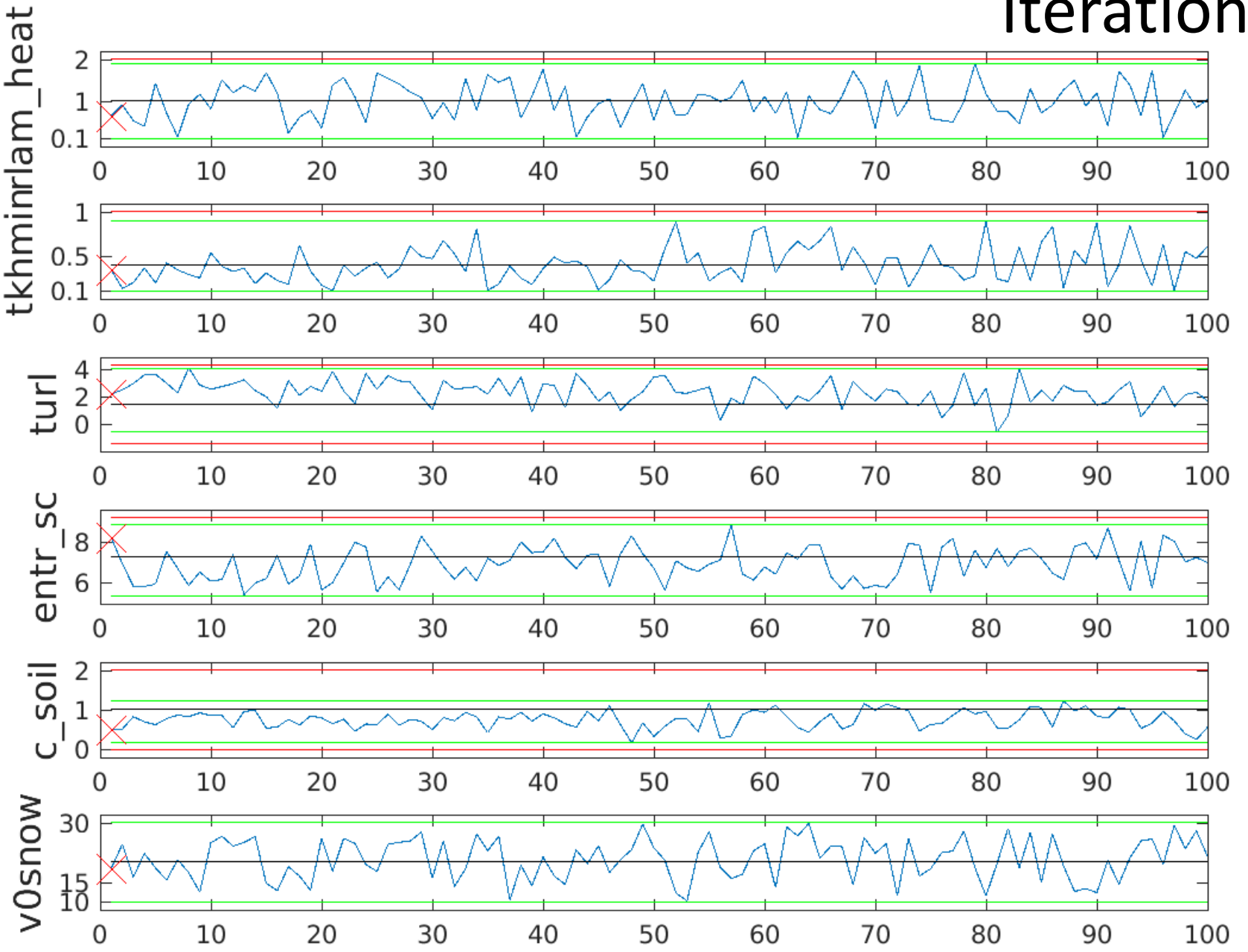
1. **Overview: from CALMO-stage1 to CALMO-stage2**
2. **Adaptations to the Meta-Model**
   - Option not to average Tmax/Tmin over regions
   - Meta-Model predicts profiles characteristics
   - Defining new regions
   - Performance scores
     - RMSE-type score
     - COSI-type score
   - Logarithmic transformation for some of the parameters
   - Convergence to the optimal parameters combination
3. **Calibration results**
4. **Summary**

Convergence to the optimal parameters combination

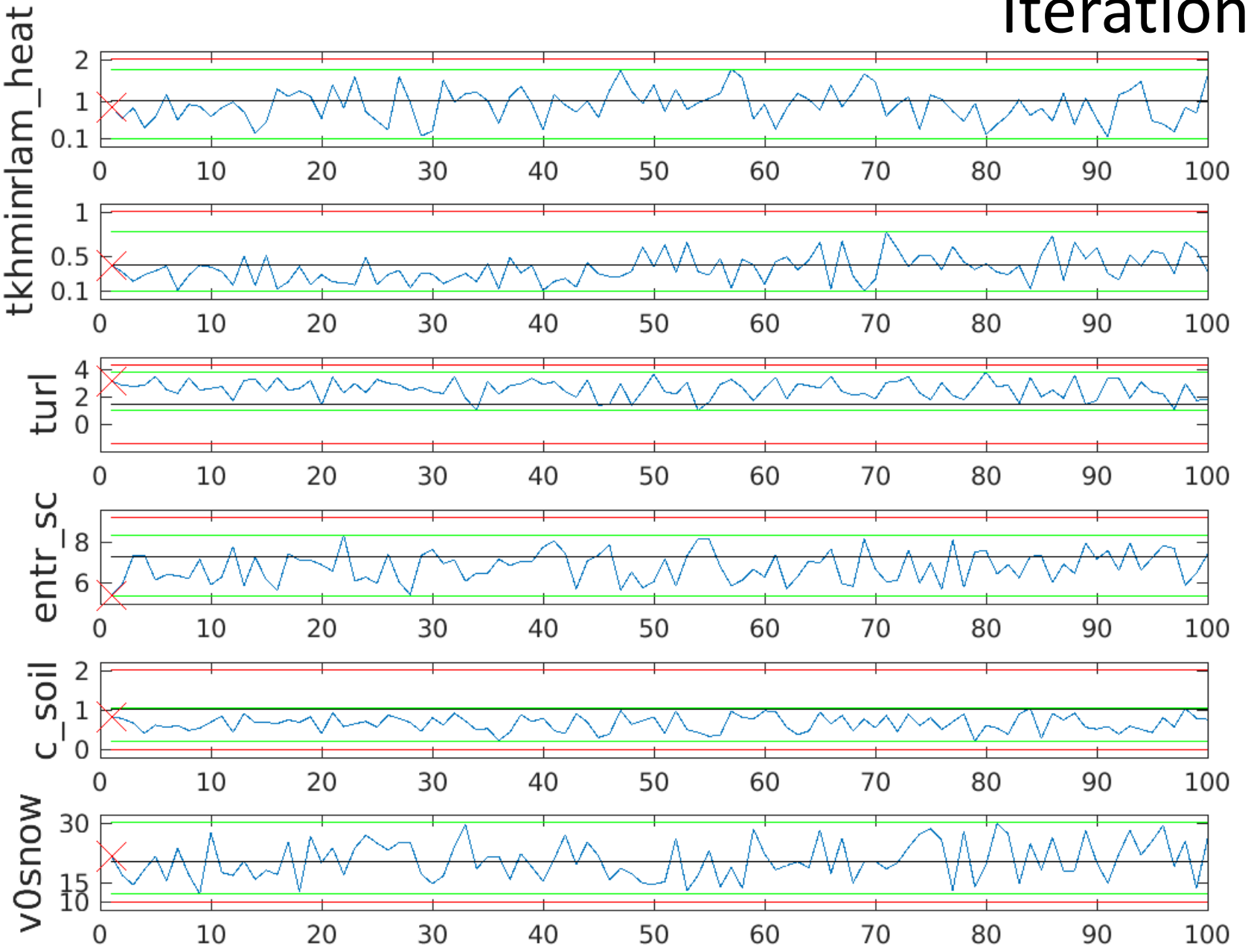
In CALMO-stage1, we have calibrated 3 parameters, dividing the parameters space into 10000 points, i.e. roughly 21 bins for each of the parameters. In CALMO-stage2, the number of calibrated parameters is 6, yielding huge number (about $21^6 \approx 10^8$) of points to be evaluated in order to find the optimal one. However, for computer time reasons it is not possible.

Recently we have developed a method to overcome that problem and converge to the optimal parameters combination. At first iteration we sample 1000 points only and reveal the optimal regions in our 6 dimensional parameters space. At second iteration we sample those regions by additional 1000 points, and reveal new, smaller, optimal regions. We continue with these iterations (roughly 25) until the solution converges to the optimal parameters combination.

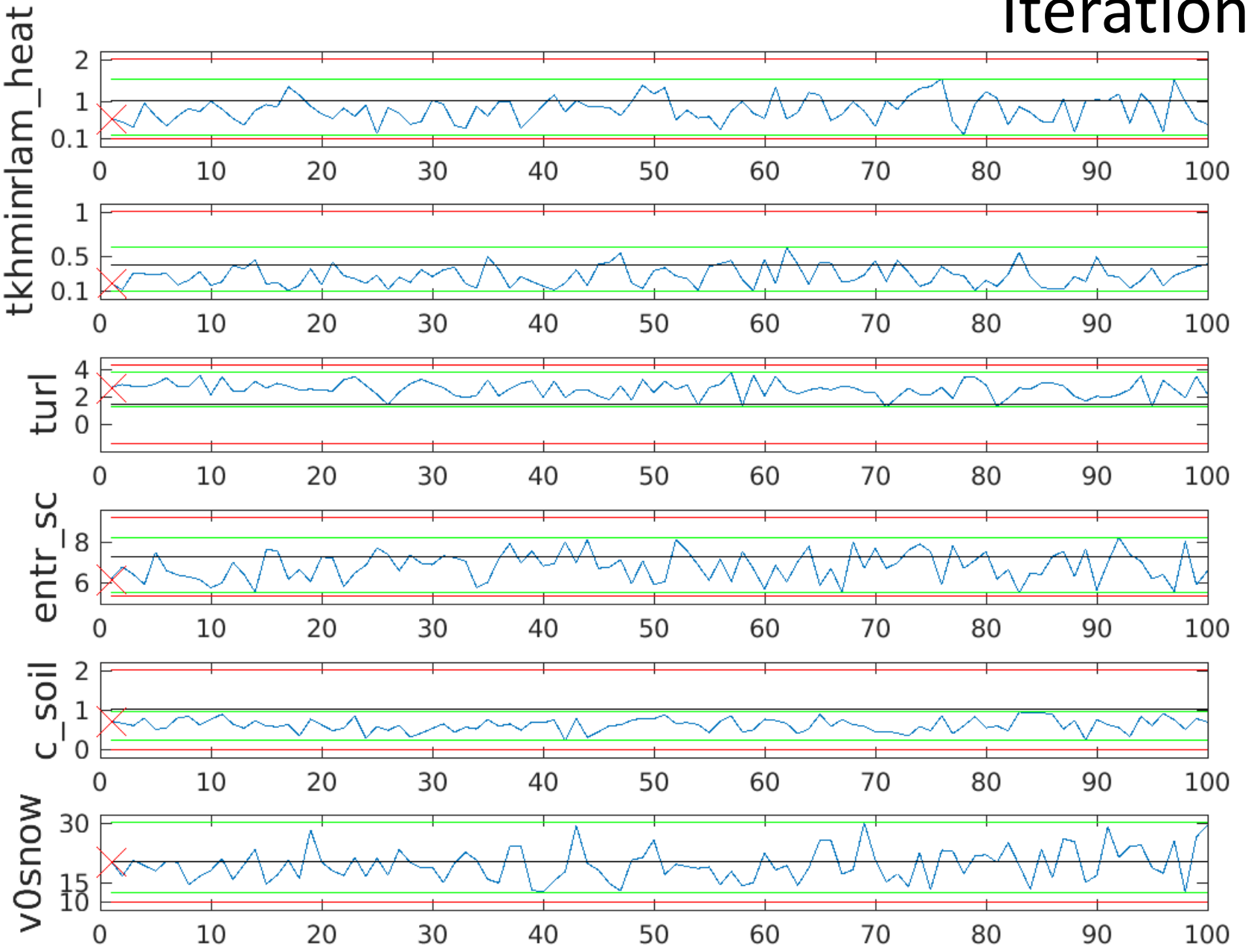
Iteration 1


tkhminrlam_heat
2
1
0.1
0
10
20
30
40
50
60
70
80
90
100
1
0.5
0.1
turl
4
2
0
entr_sc
8
6
c_soil
v0snow
30
15
10

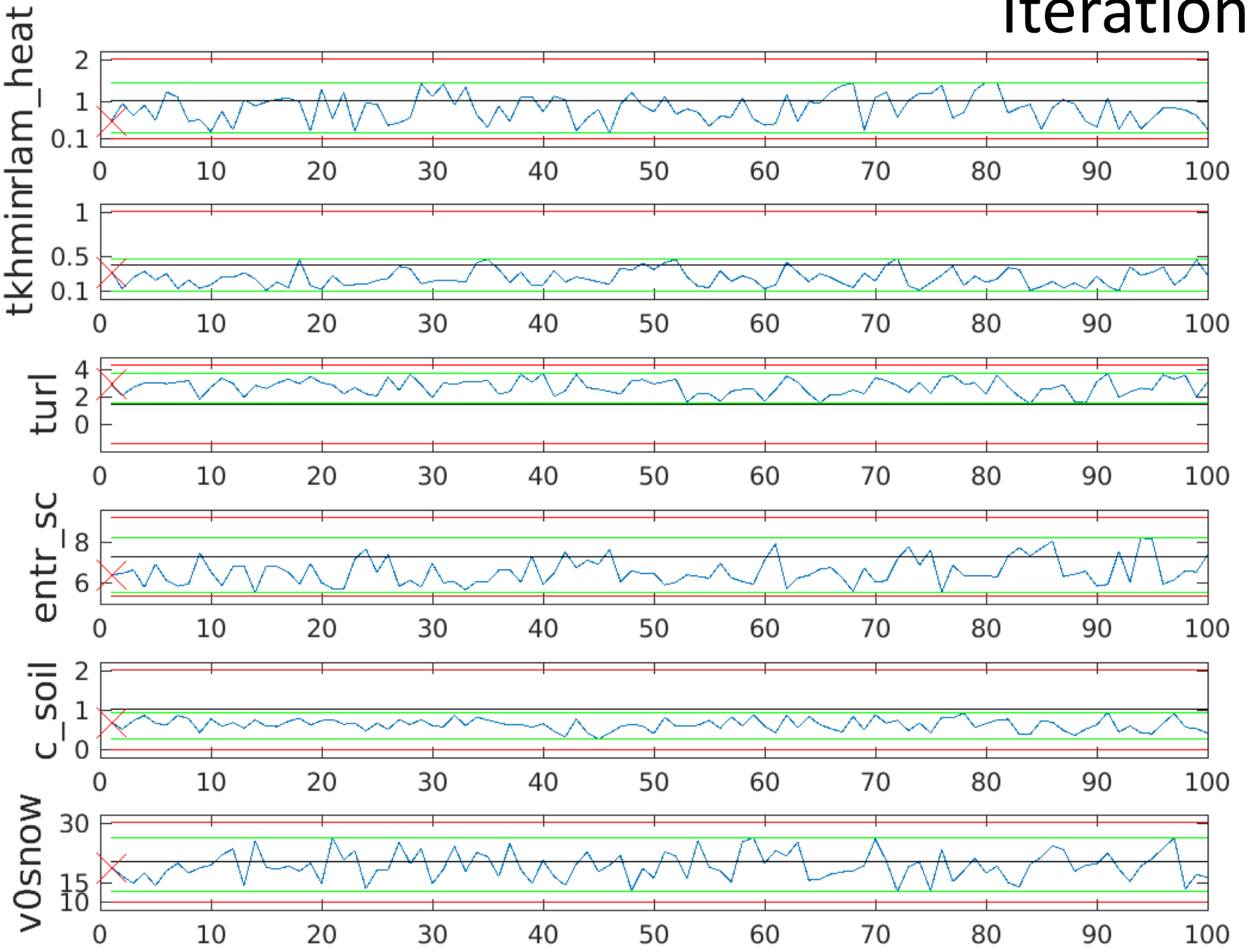
Iteration 2


tkhminrlam_heat
2
1
0.1
0 10 20 30 40 50 60 70 80 90 100
1
0.5
0.1
0 10 20 30 40 50 60 70 80 90 100
turl
4
2
0
0 10 20 30 40 50 60 70 80 90 100
entr_sc
8
6
0 10 20 30 40 50 60 70 80 90 100
c_soil
2
1
0
0 10 20 30 40 50 60 70 80 90 100
v0snow
30
15
10
0 10 20 30 40 50 60 70 80 90 100

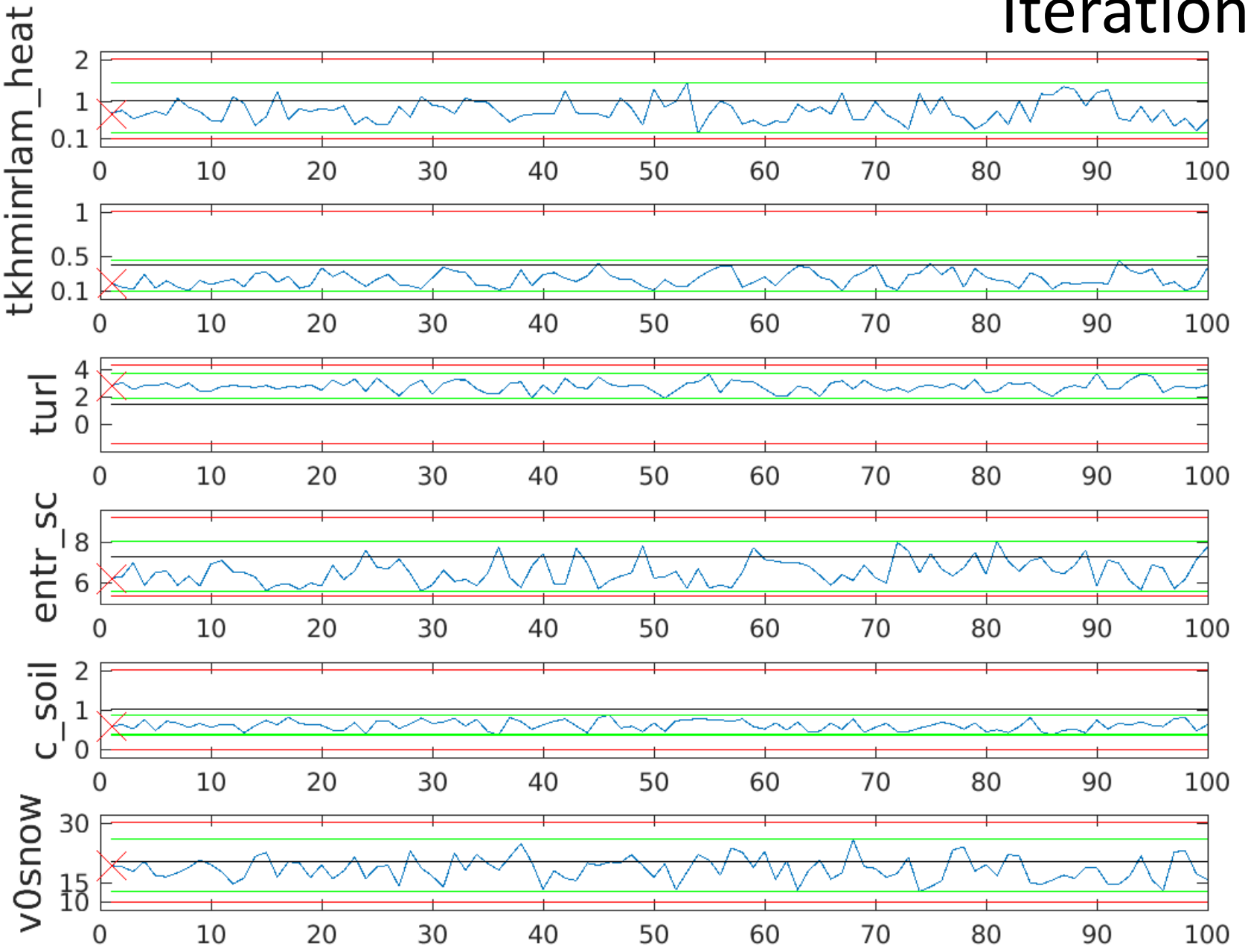
Iteration 3


tkhminrlam_heat
2
1
0.1
0 10 20 30 40 50 60 70 80 90 100
1
0.5
0.1
0 10 20 30 40 50 60 70 80 90 100
turl
4
2
0
0 10 20 30 40 50 60 70 80 90 100
entr_sc
8
6
0 10 20 30 40 50 60 70 80 90 100
c_soil
2
1
0
0 10 20 30 40 50 60 70 80 90 100
v0snow
30
15
10
0 10 20 30 40 50 60 70 80 90 100

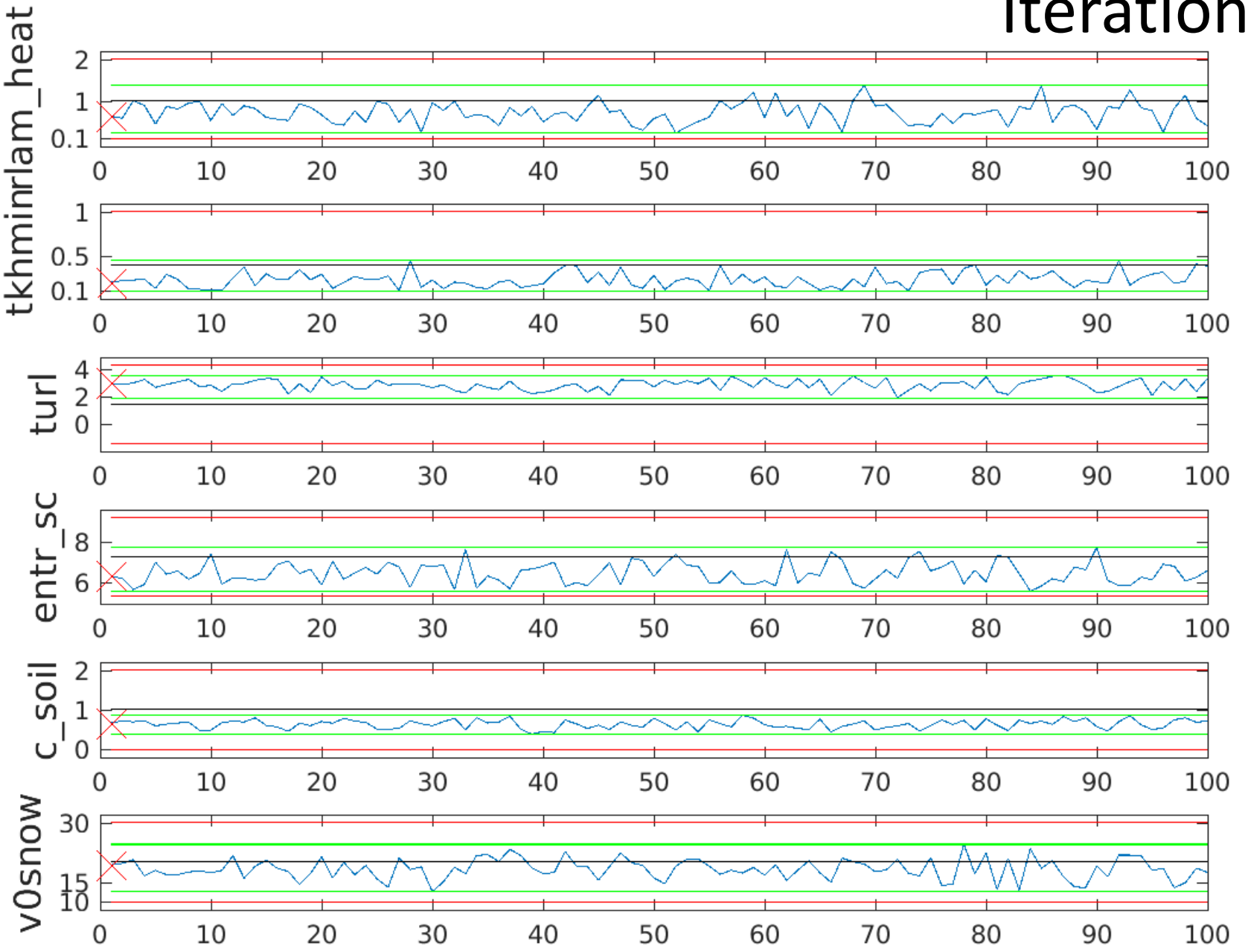
Iteration 4


tkhminrlam_heat
2
1
0.1
0 10 20 30 40 50 60 70 80 90 100
1
0.5
0.1
0 10 20 30 40 50 60 70 80 90 100
turl
4
2
0
0 10 20 30 40 50 60 70 80 90 100
entr_sc
8
6
0 10 20 30 40 50 60 70 80 90 100
c_soil
2
1
0
0 10 20 30 40 50 60 70 80 90 100
v0snow
30
15
10
0 10 20 30 40 50 60 70 80 90 100

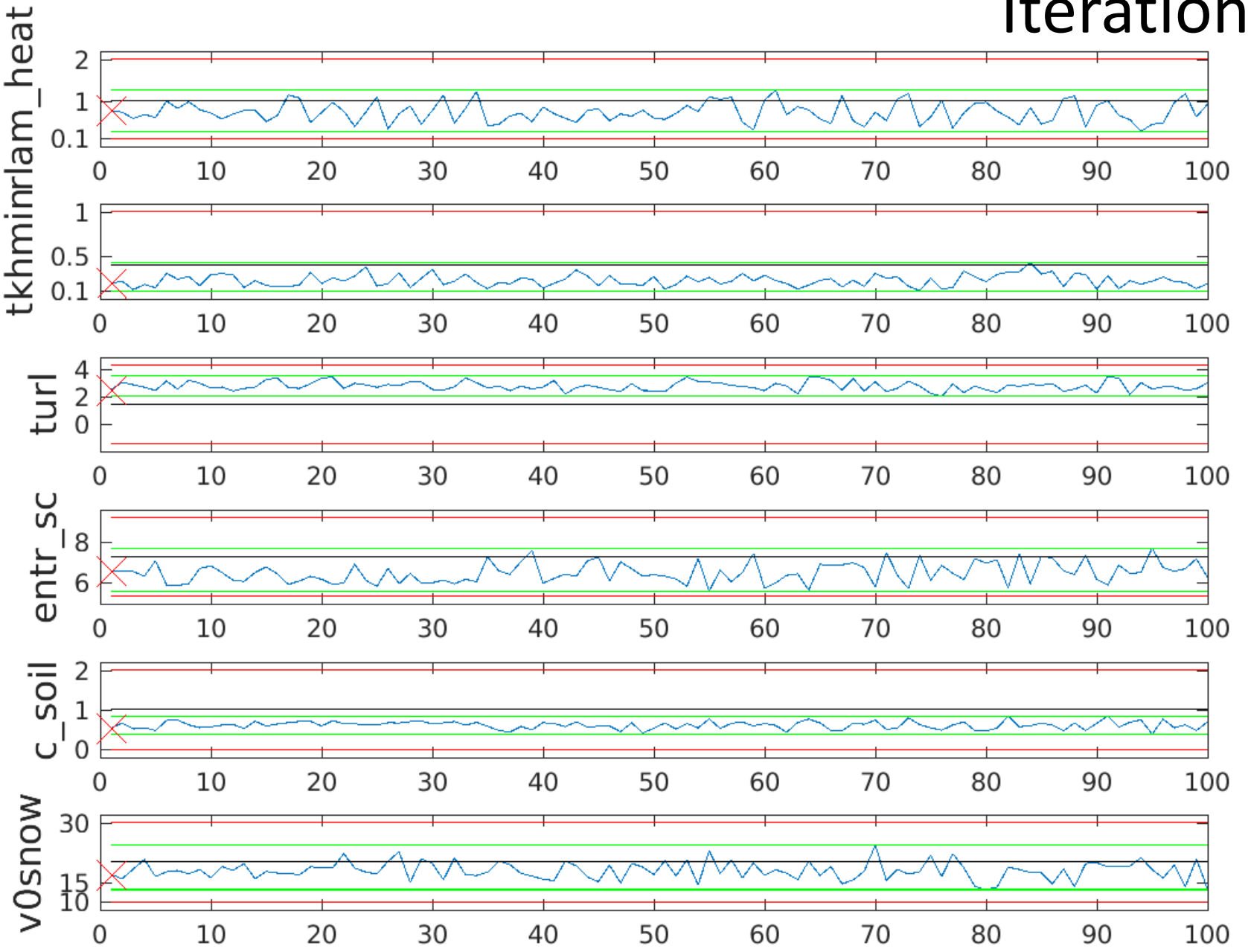
Iteration 5


tkhminrlam_heat
2
1
0.1
0 10 20 30 40 50 60 70 80 90 100
1
0.5
0.1
0 10 20 30 40 50 60 70 80 90 100
turl
4
2
0
0 10 20 30 40 50 60 70 80 90 100
entr_sc
8
6
0 10 20 30 40 50 60 70 80 90 100
c_soil
2
1
0
0 10 20 30 40 50 60 70 80 90 100
v0snow
30
15
10
0 10 20 30 40 50 60 70 80 90 100

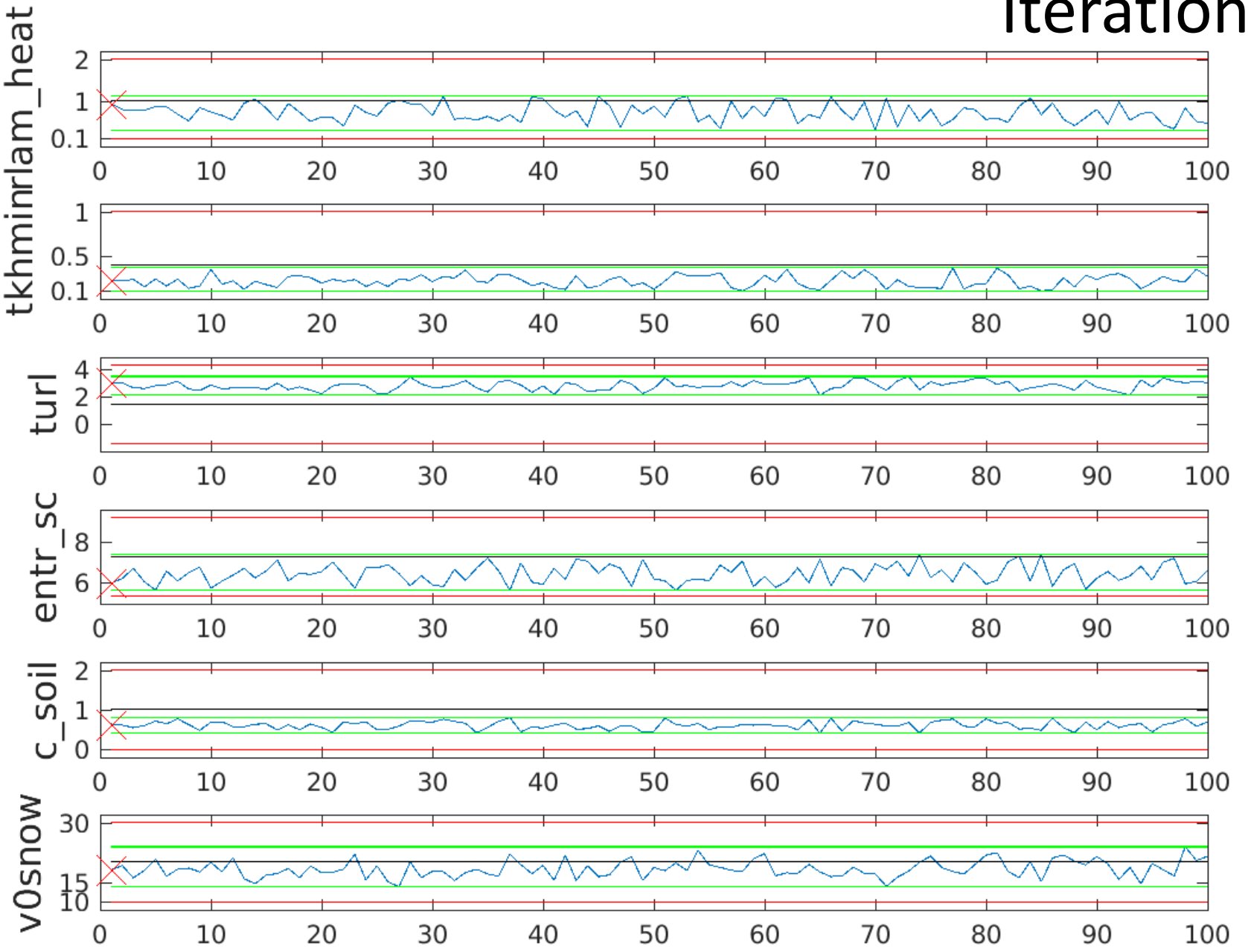
Iteration 6


tkhminrlam_heat
2
1
0.1
0 10 20 30 40 50 60 70 80 90 100
1
0.5
0.1
0 10 20 30 40 50 60 70 80 90 100
turl
4
2
0
0 10 20 30 40 50 60 70 80 90 100
entr_sc
8
6
0 10 20 30 40 50 60 70 80 90 100
c_soil
2
1
0
0 10 20 30 40 50 60 70 80 90 100
v0snow
30
15
10
0 10 20 30 40 50 60 70 80 90 100

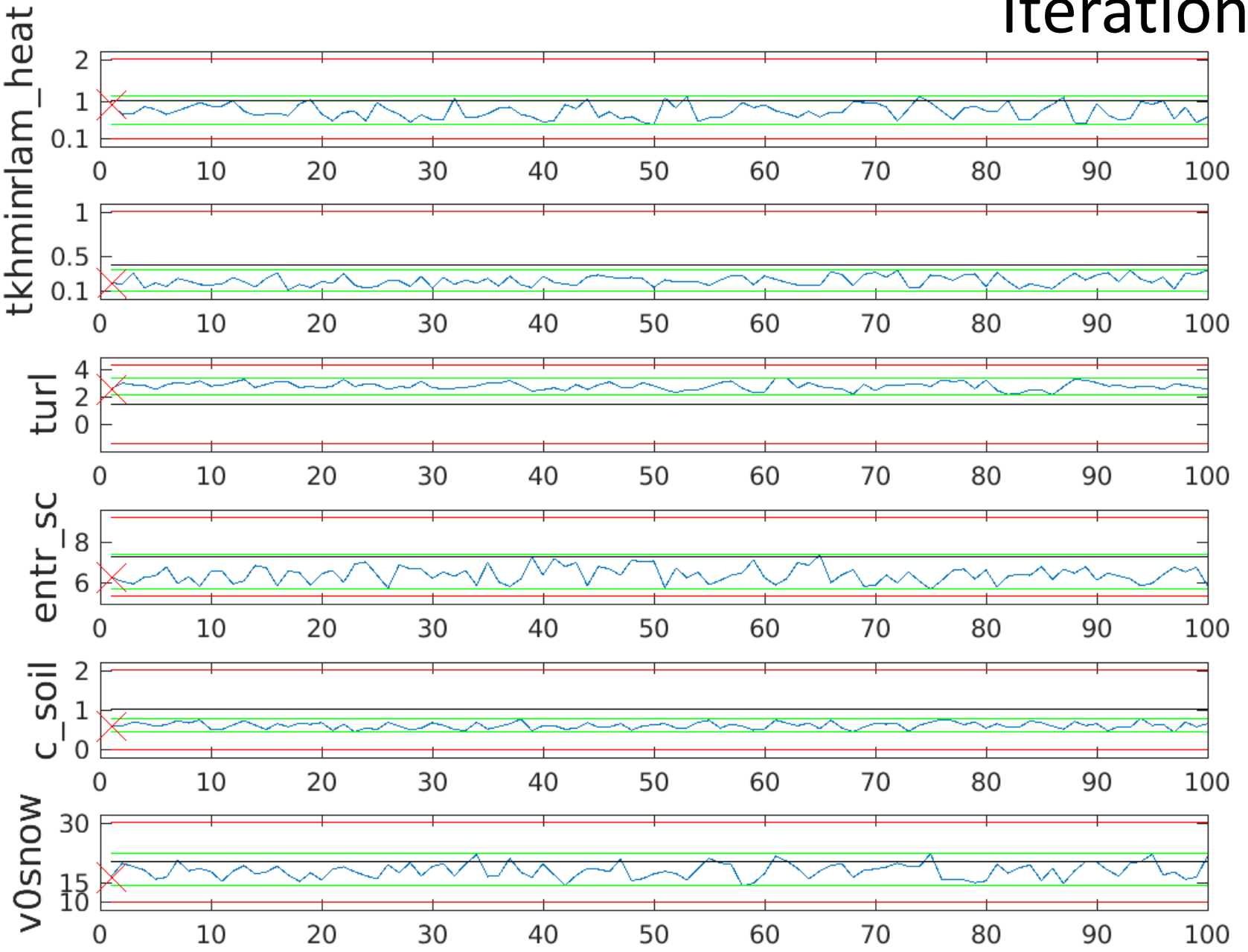
Iteration 7


tkhminrlam_heat
2
1
0.1
0 10 20 30 40 50 60 70 80 90 100
1
0.5
0.1
0 10 20 30 40 50 60 70 80 90 100
turl
4
2
0
0 10 20 30 40 50 60 70 80 90 100
entr_sc
8
6
0 10 20 30 40 50 60 70 80 90 100
c_soil
2
1
0
0 10 20 30 40 50 60 70 80 90 100
v0snow
30
15
10
0 10 20 30 40 50 60 70 80 90 100

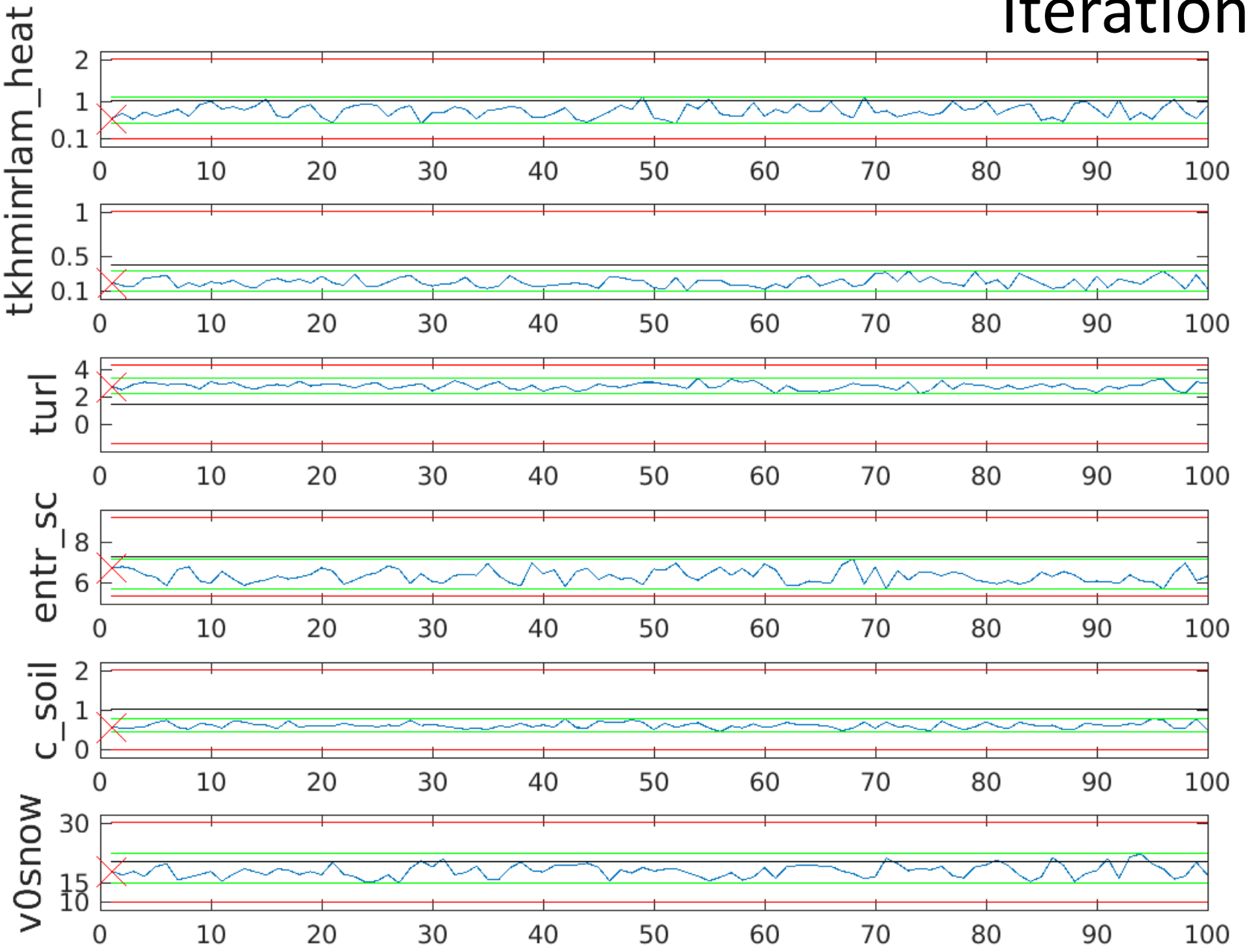
Iteration 8


tkhminrlam_heat
2
1
0.1
0
10
20
30
40
50
60
70
80
90
100
1
0.5
0.1
turl
4
2
0
entr_sc
8
6
c_soil
v0snow
30
15
10

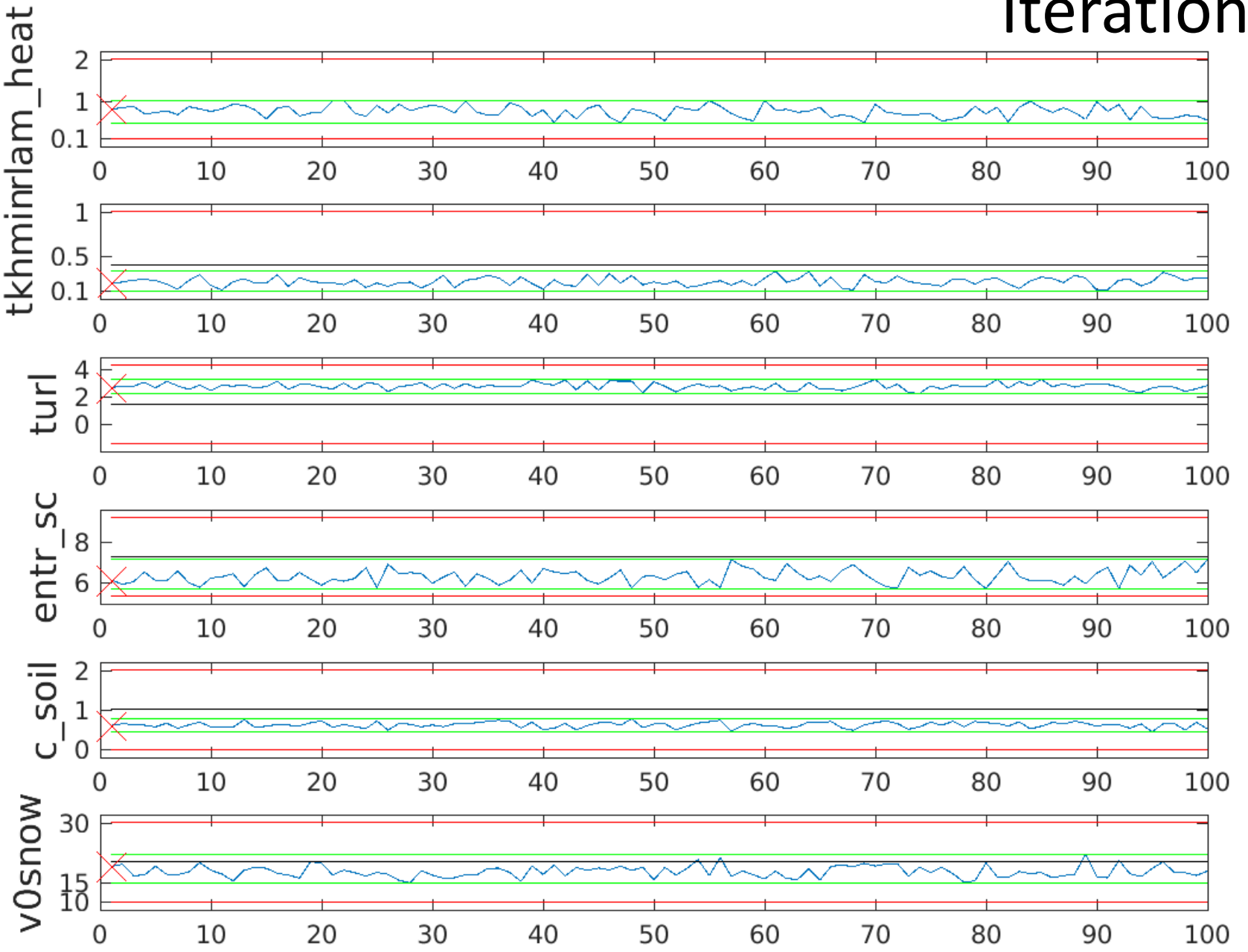
Iteration 9


tkhminrlam_heat
2
1
0.1
0 10 20 30 40 50 60 70 80 90 100
1
0.5
0.1
0 10 20 30 40 50 60 70 80 90 100
turl
4
2
0
0 10 20 30 40 50 60 70 80 90 100
entr_sc
8
6
0 10 20 30 40 50 60 70 80 90 100
c_soil
2
1
0
0 10 20 30 40 50 60 70 80 90 100
v0snow
30
15
10
0 10 20 30 40 50 60 70 80 90 100

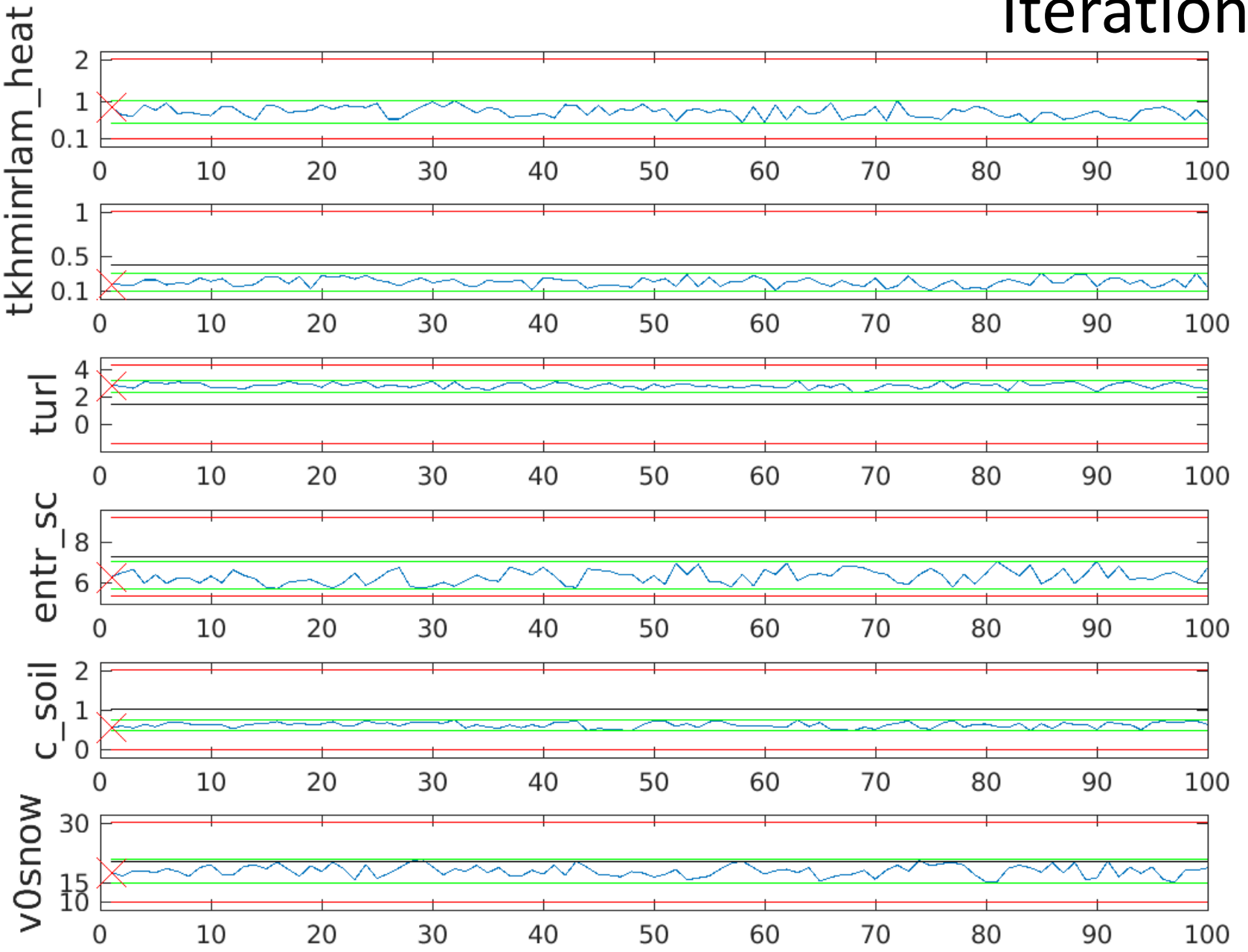
Iteration 10



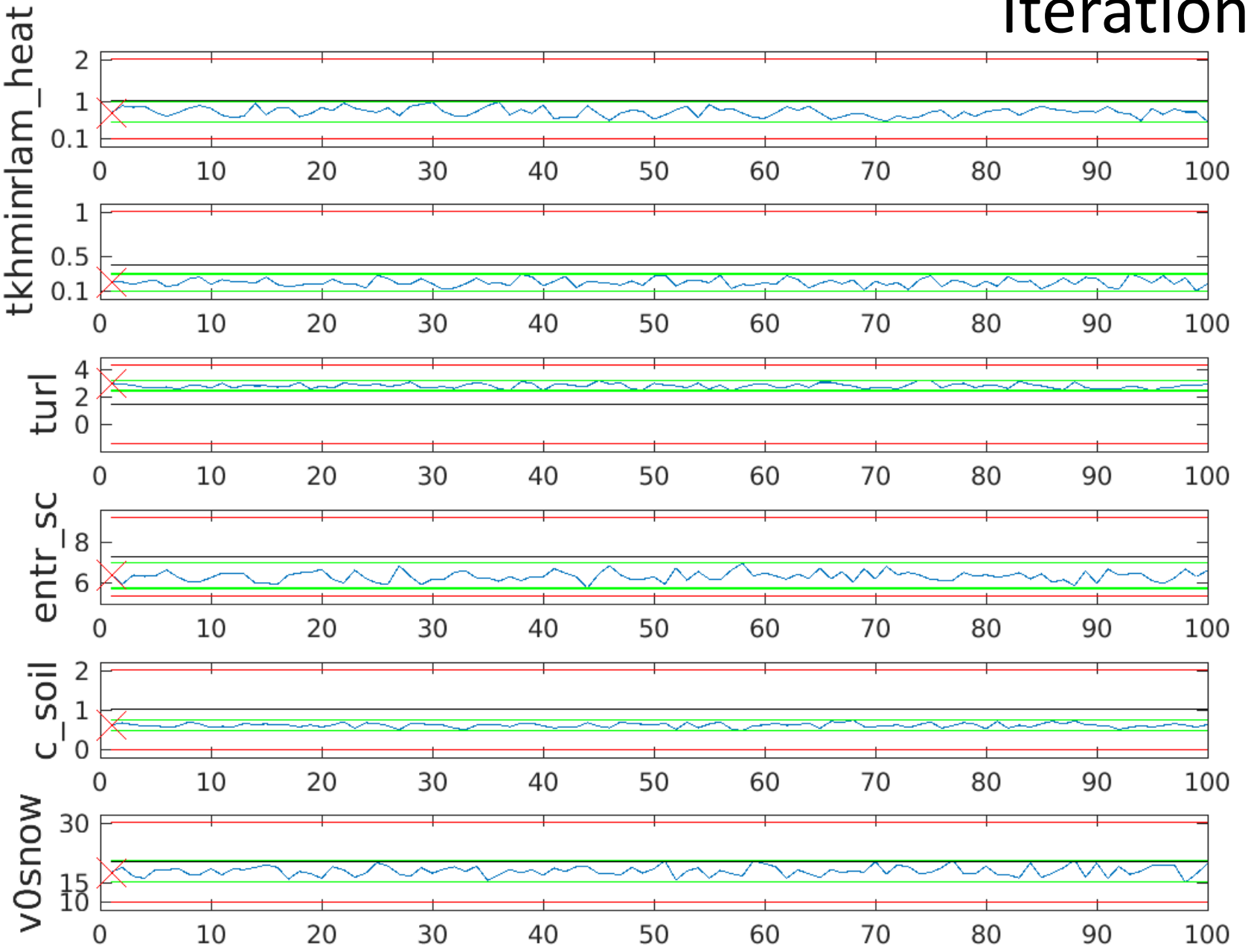
Iteration 11



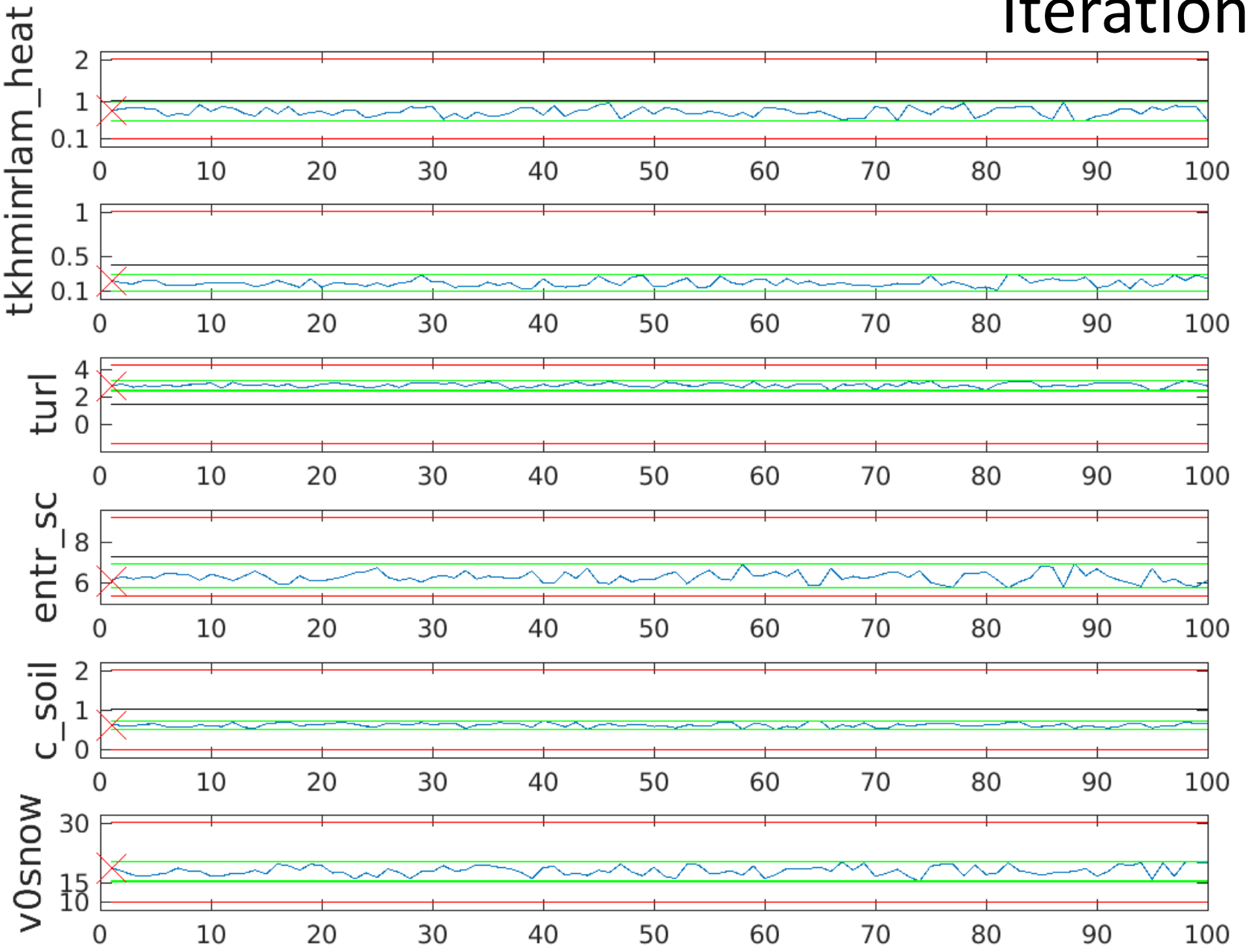
Iteration 12



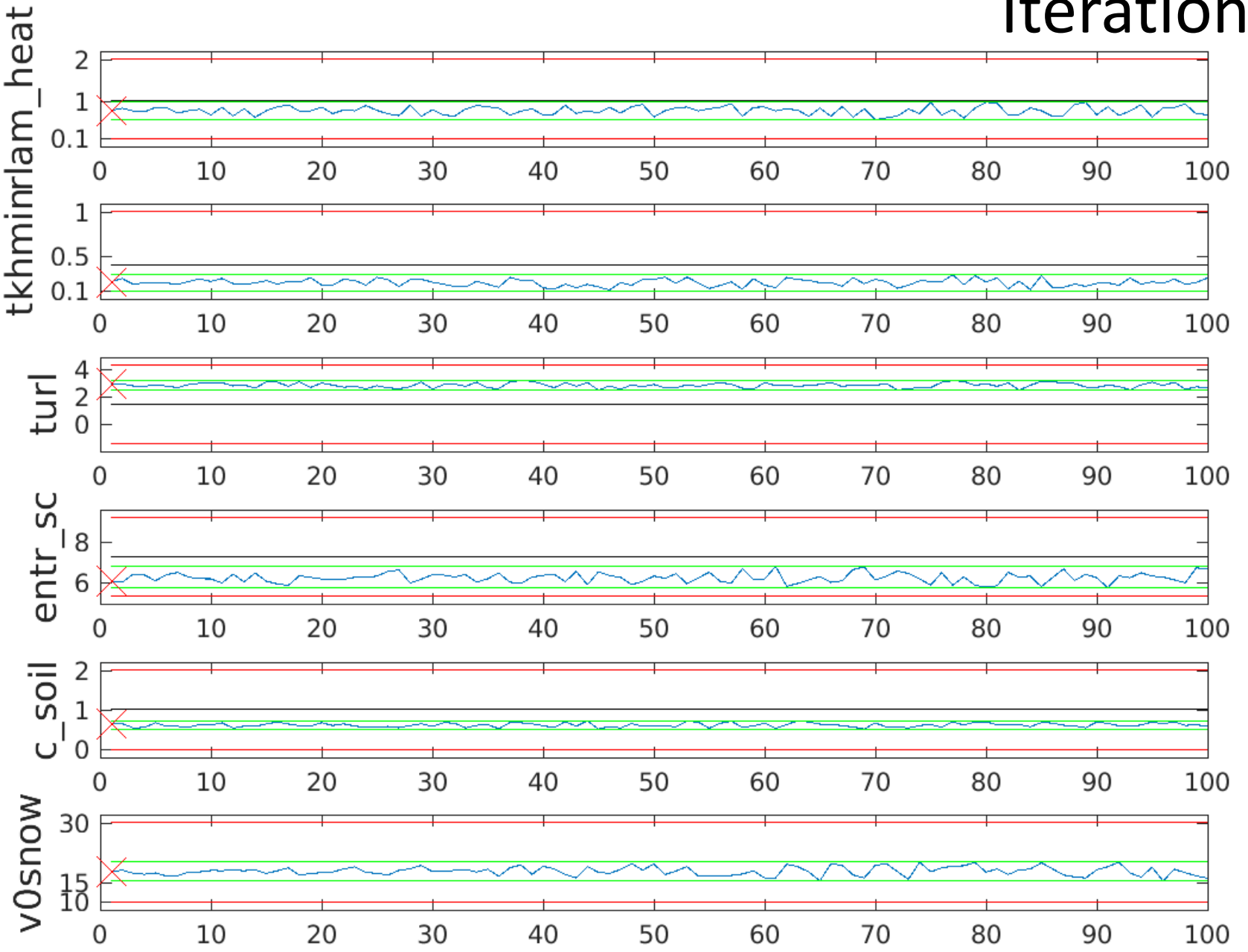
Iteration 13



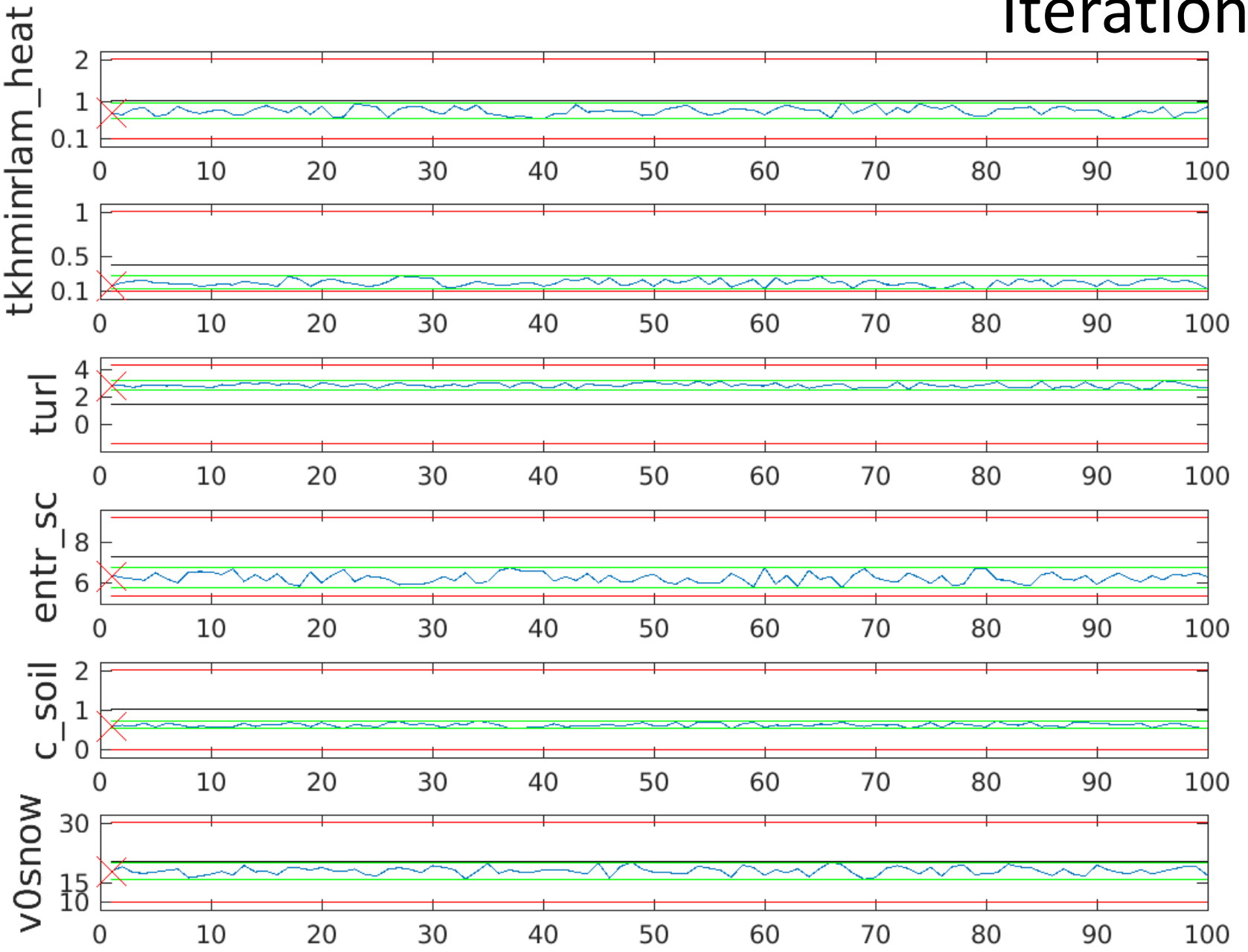
Iteration 14



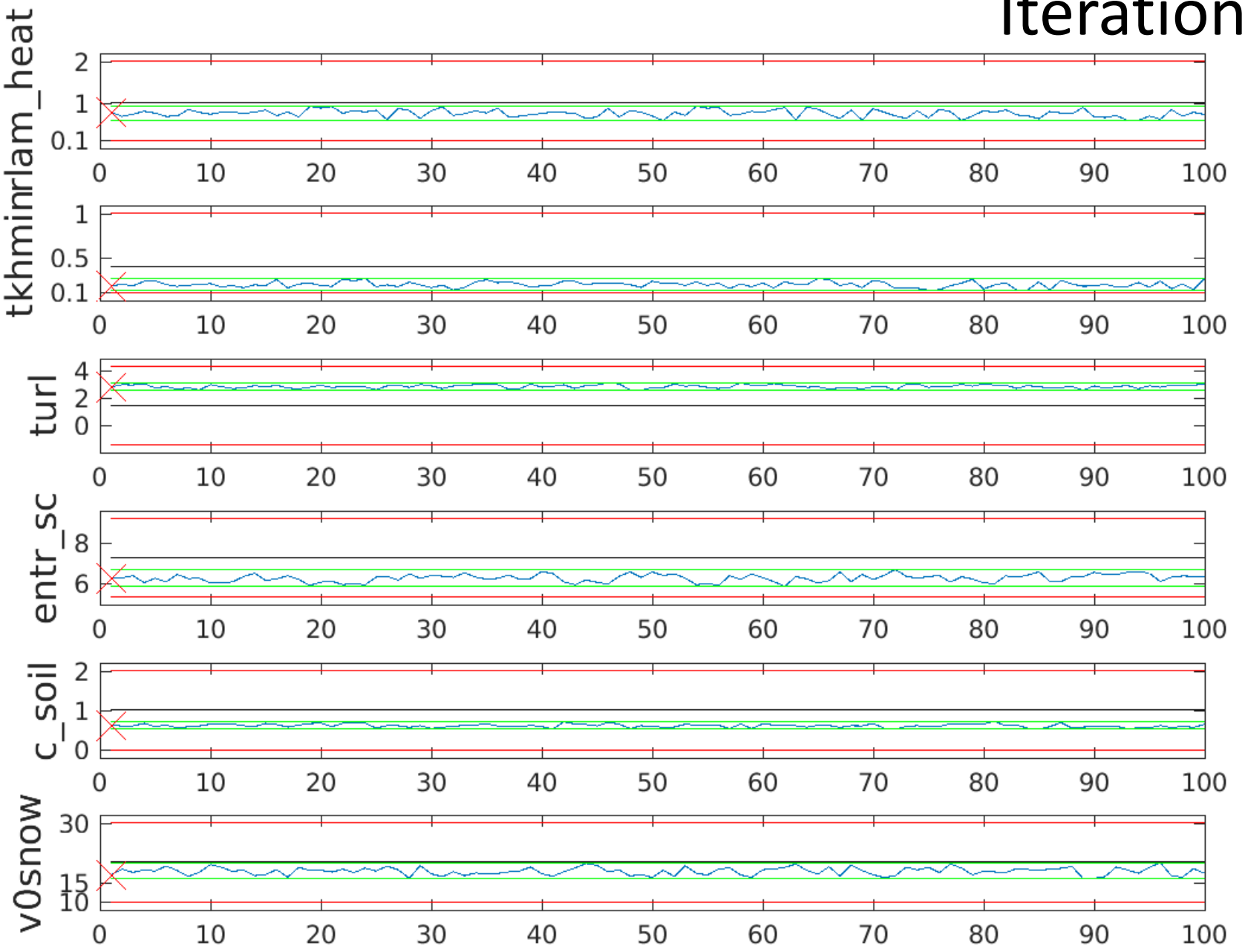
Iteration 15



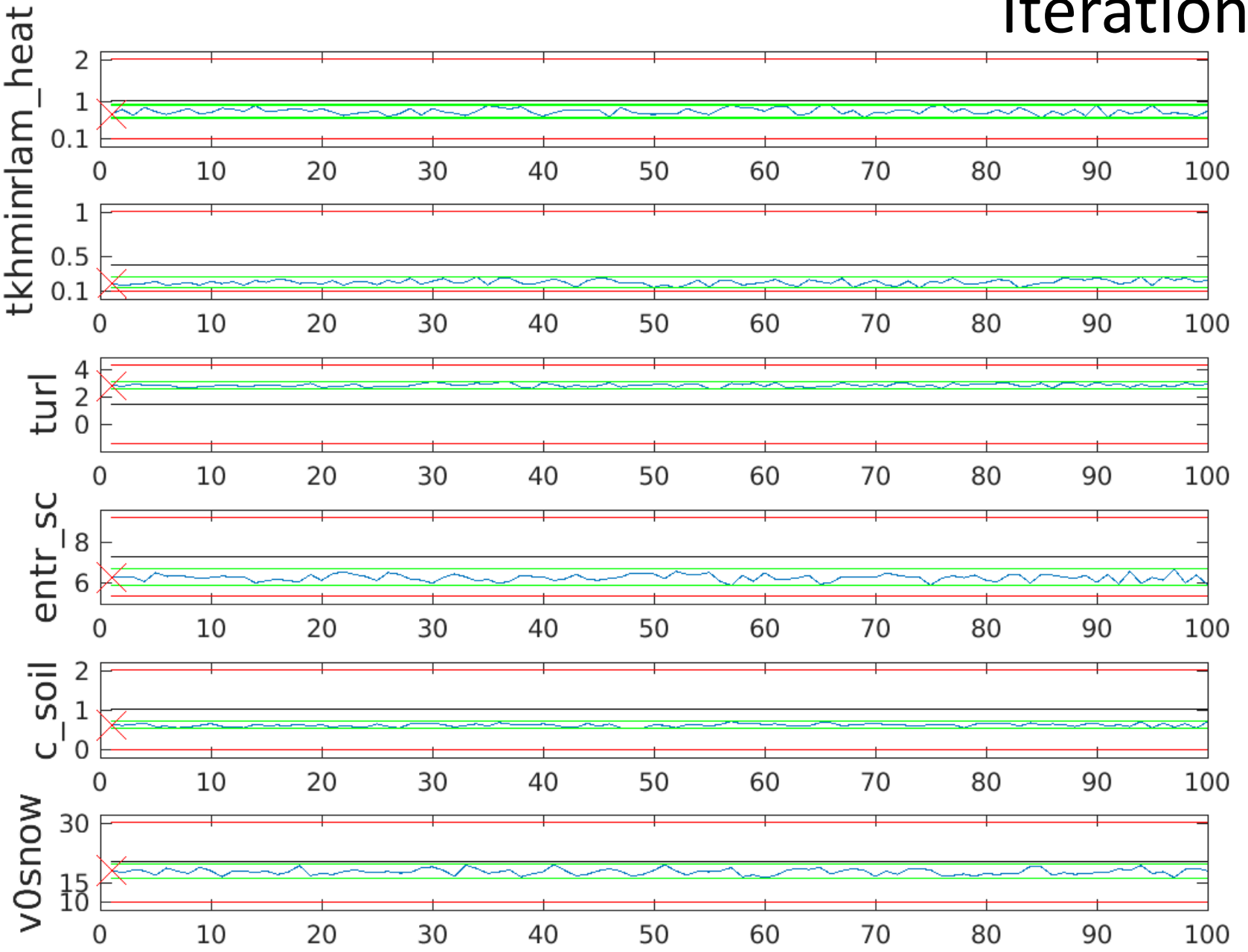
Iteration 16



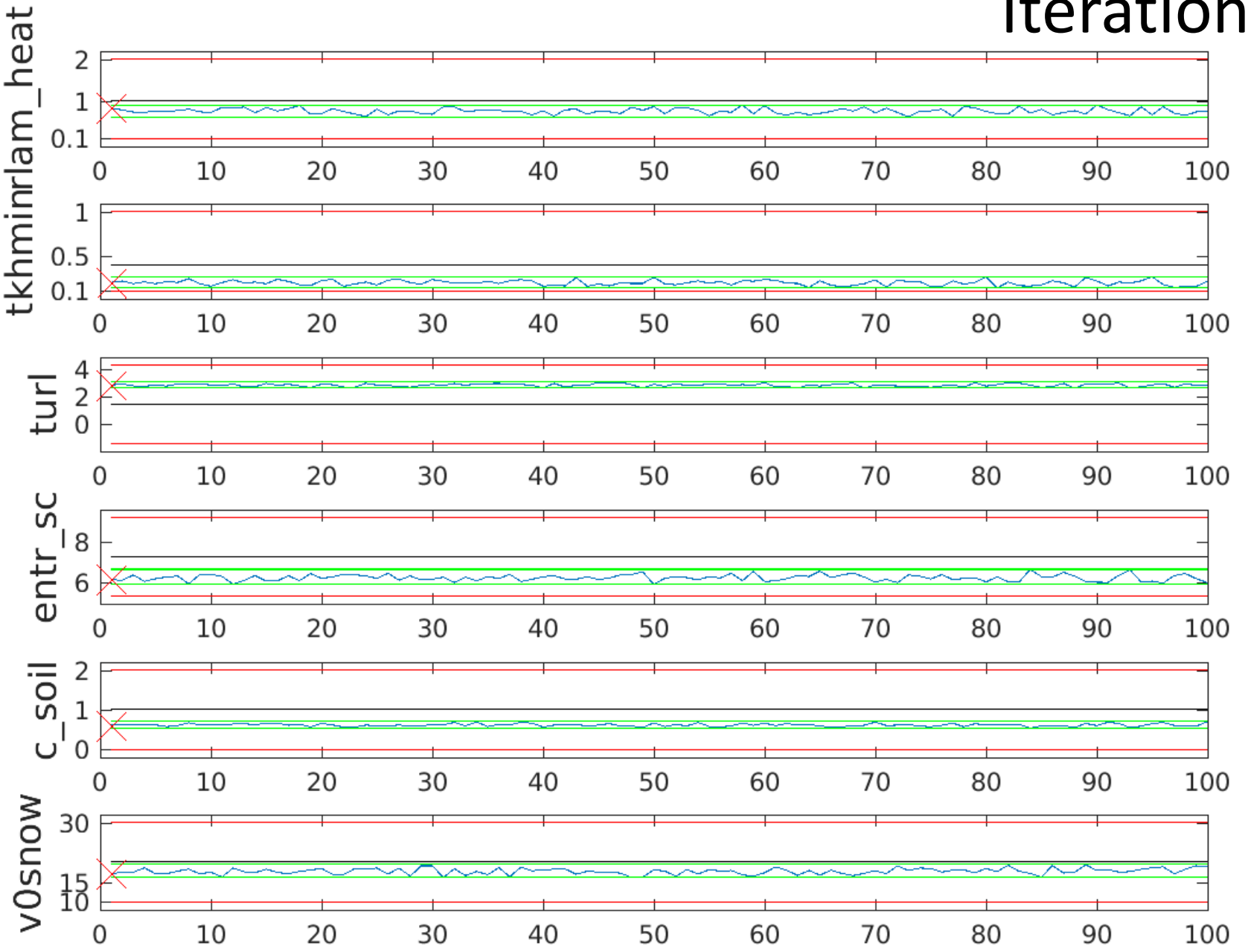
Iteration 17



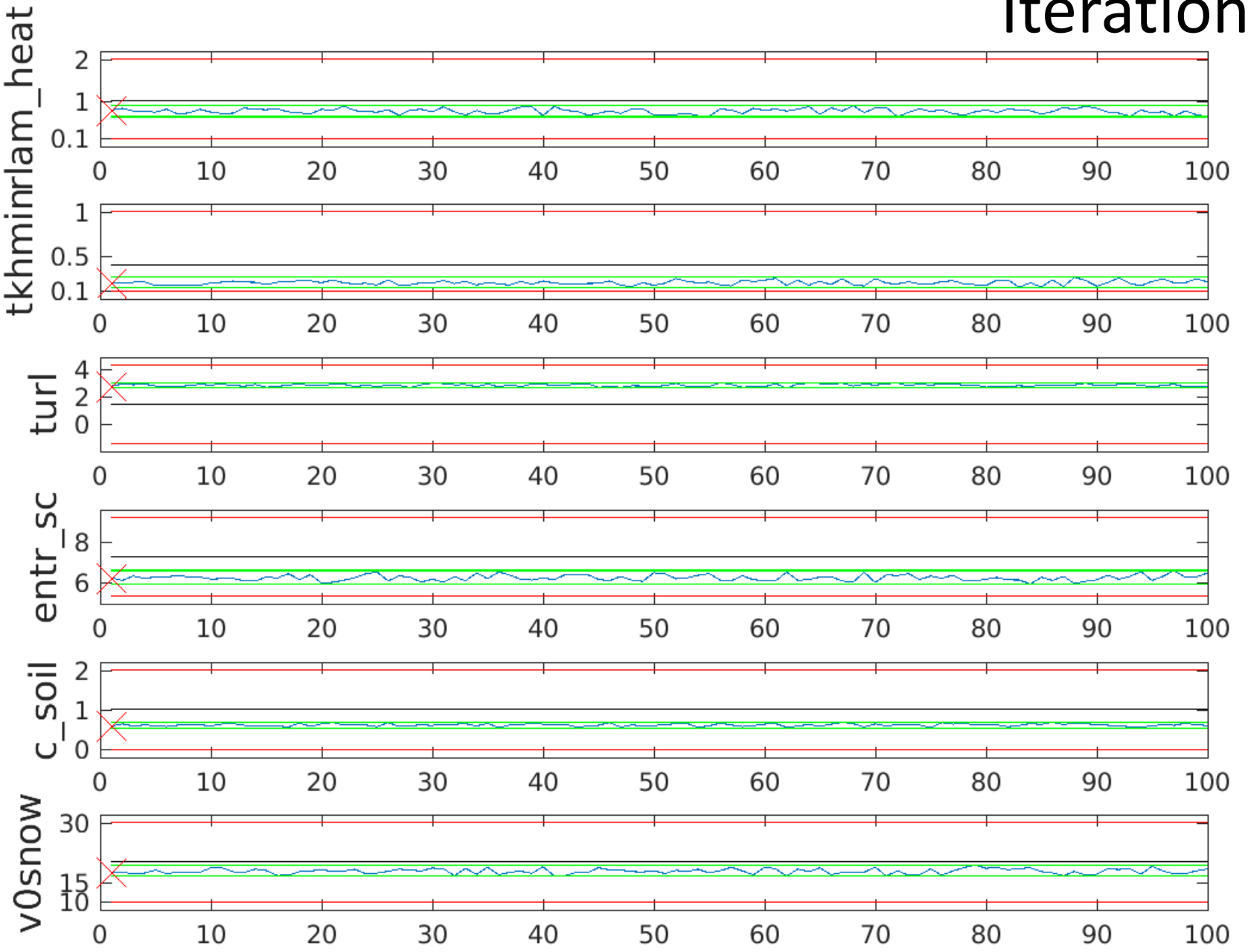
Iteration 18



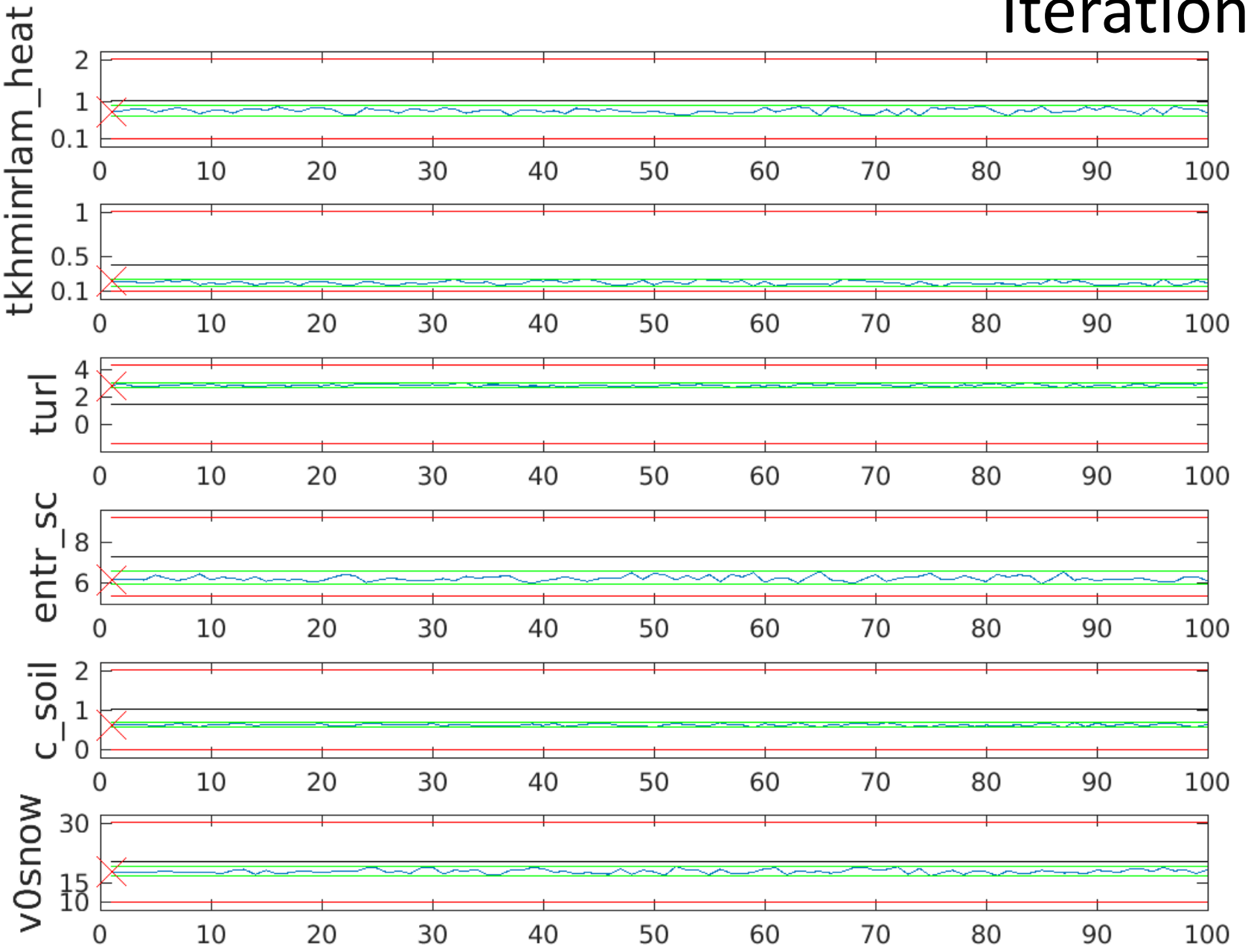
Iteration 19



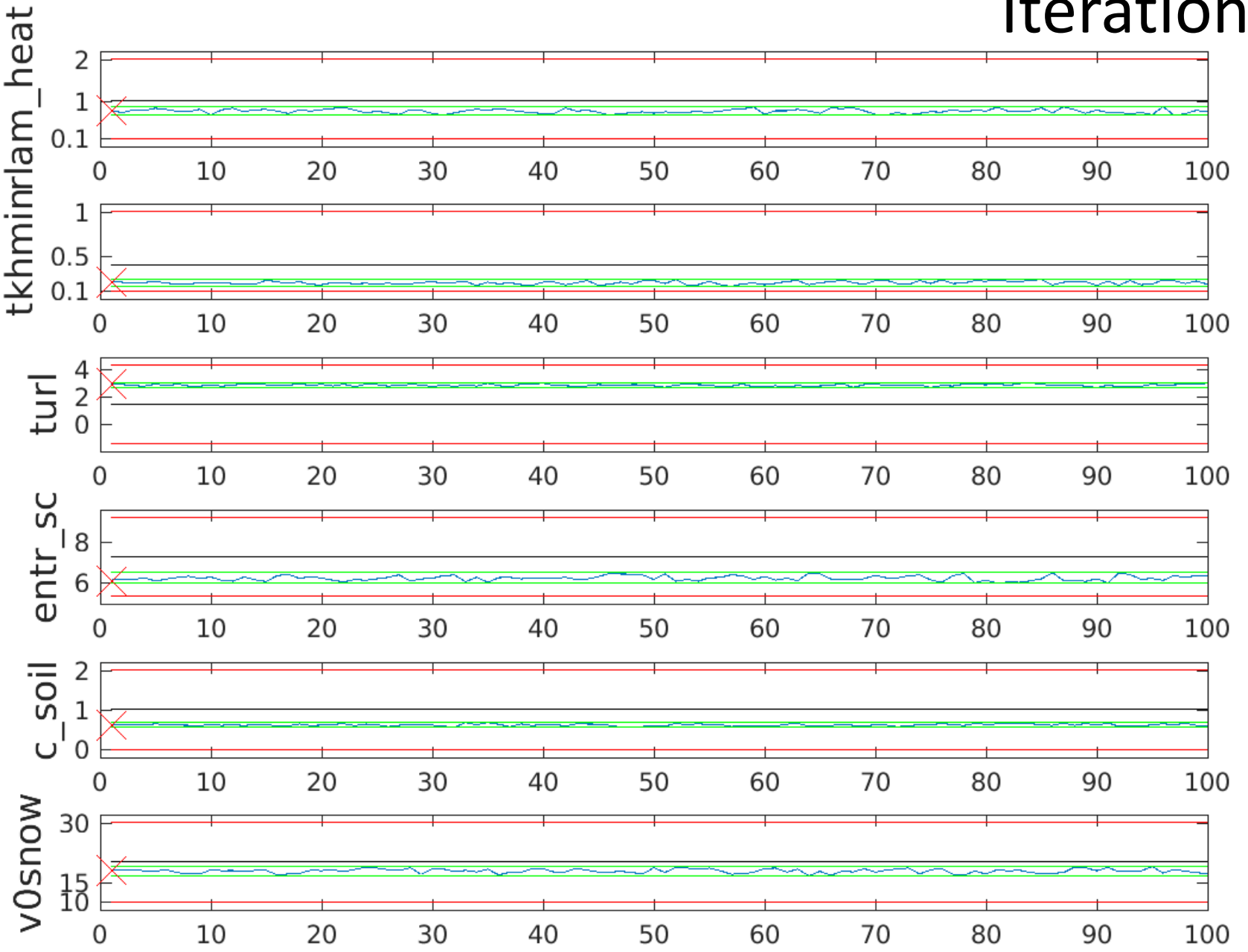
Iteration 20



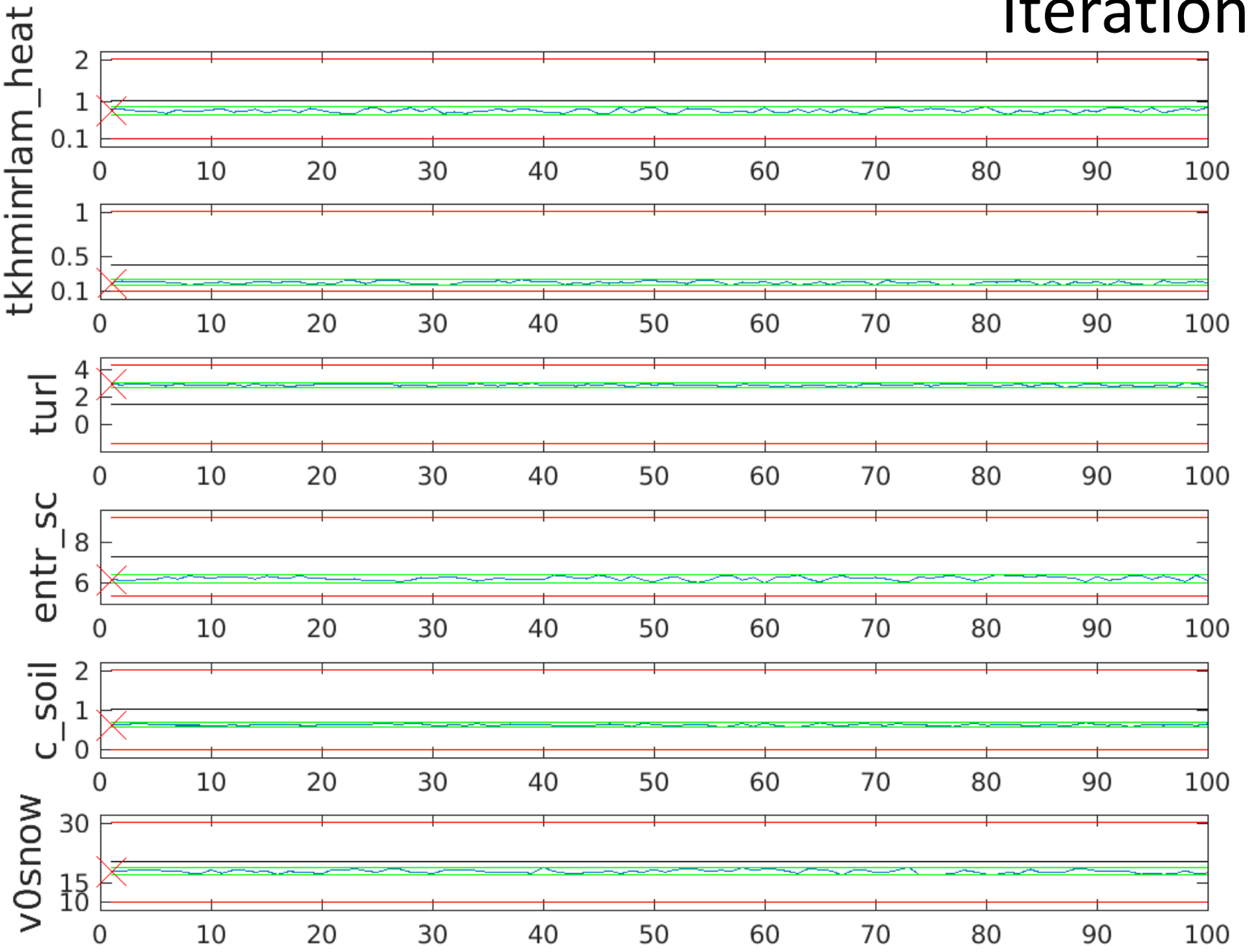
Iteration 21



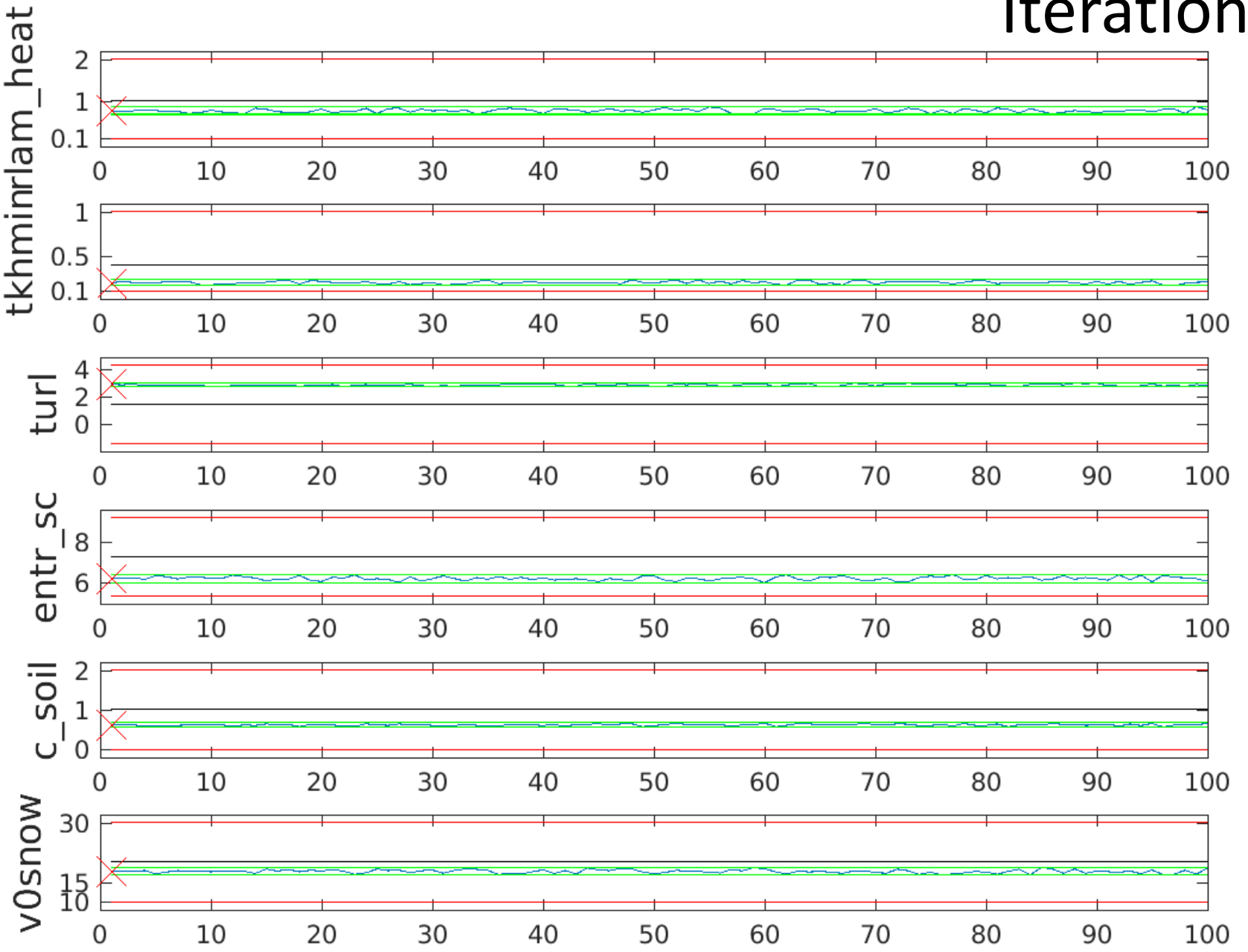
Iteration 22



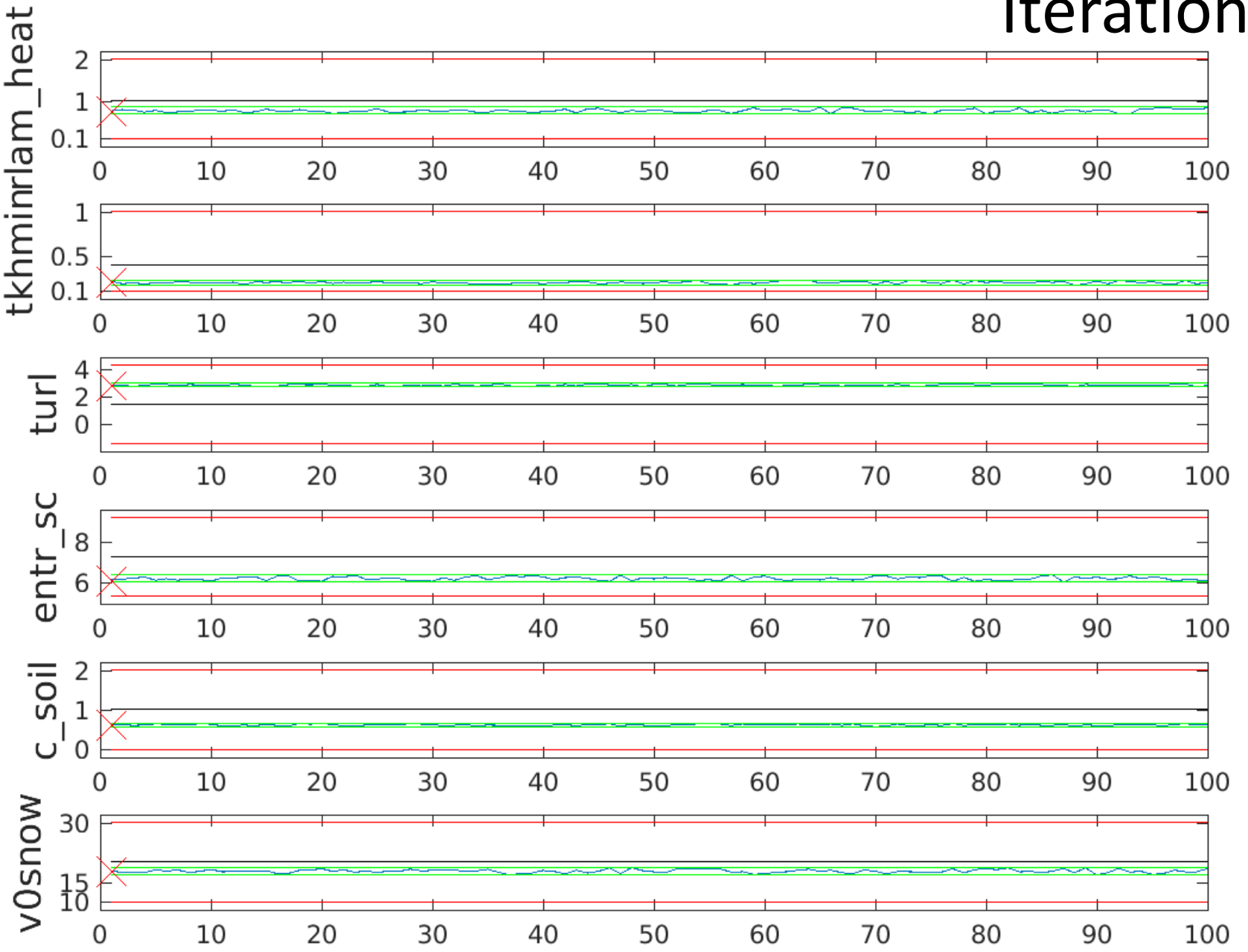
Iteration 23



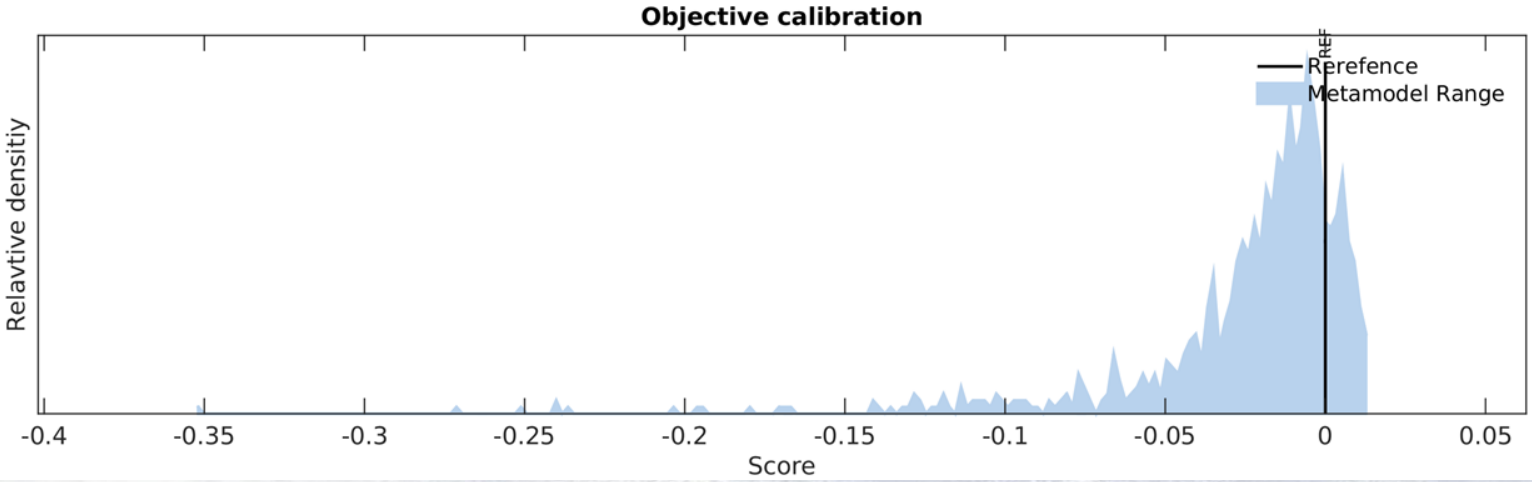
Iteration 24



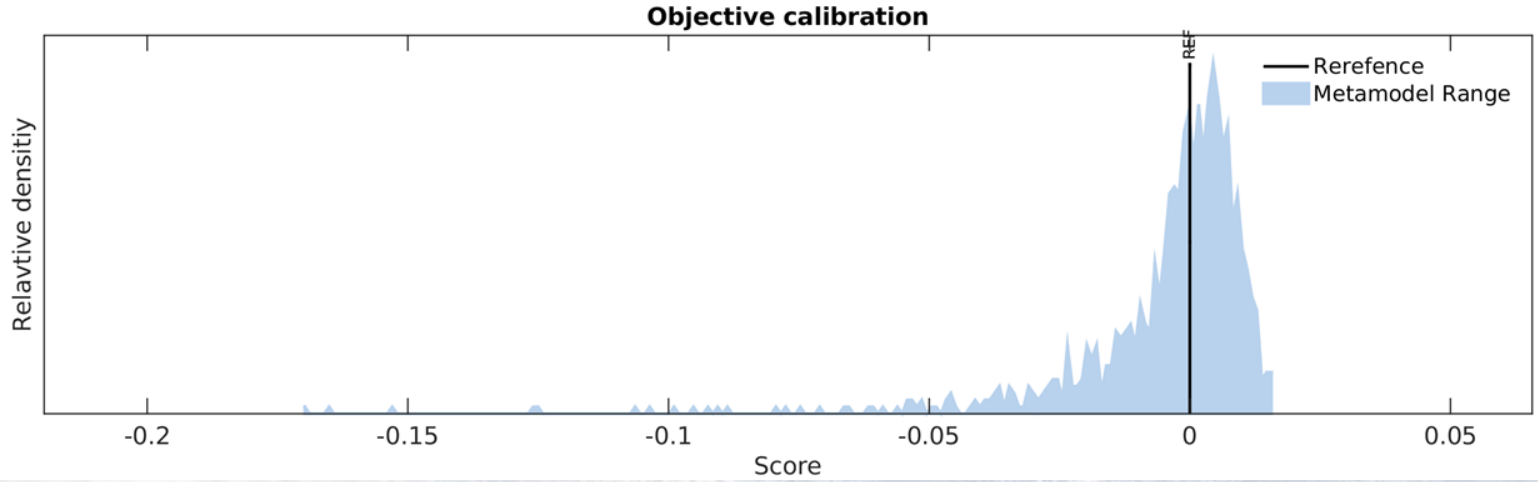
Iteration 25



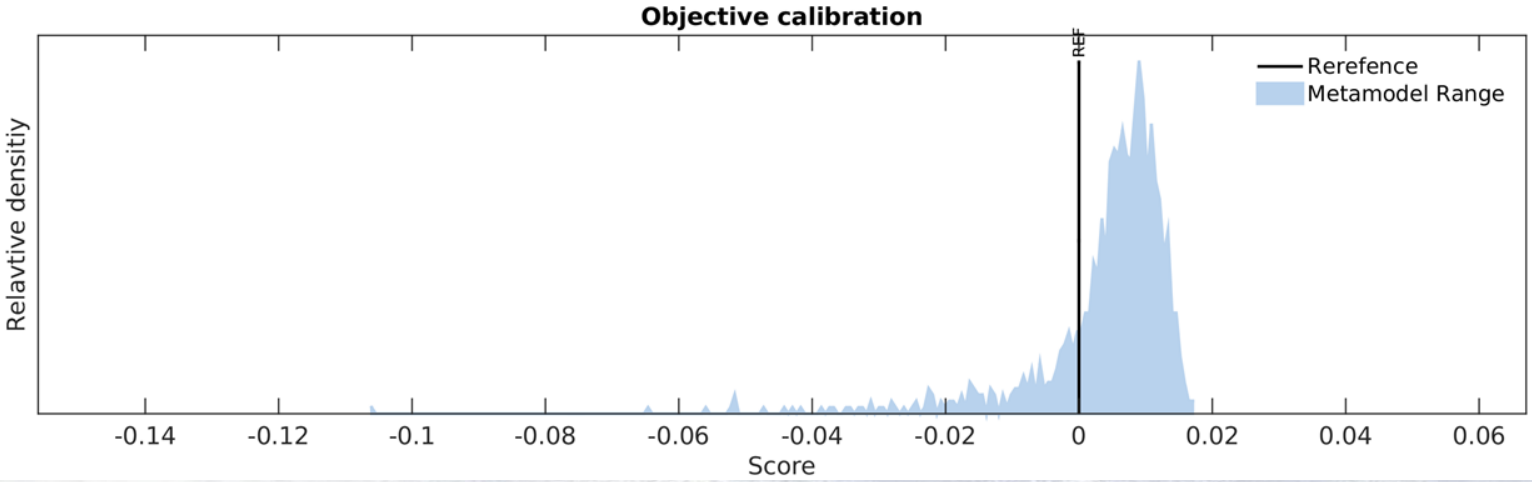
Iteration 1


Objective calibration
Relavtive densitiy
Score
Rerefence
Metamodel Range
REF
-0.4
-0.35
-0.3
-0.25
-0.2
-0.15
-0.1
-0.05
0
0.05

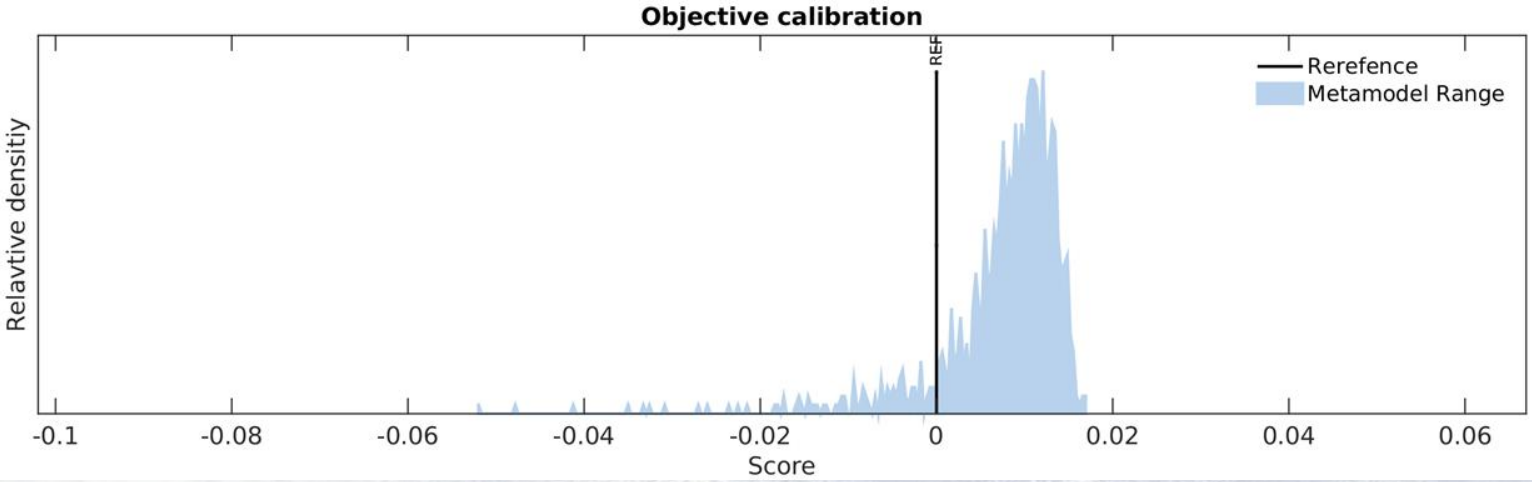
Iteration 2


Objective calibration
Relavtive densitiy
Score
-0.2
-0.15
-0.1
-0.05
0
0.05
REF
Rerefence
Metamodel Range

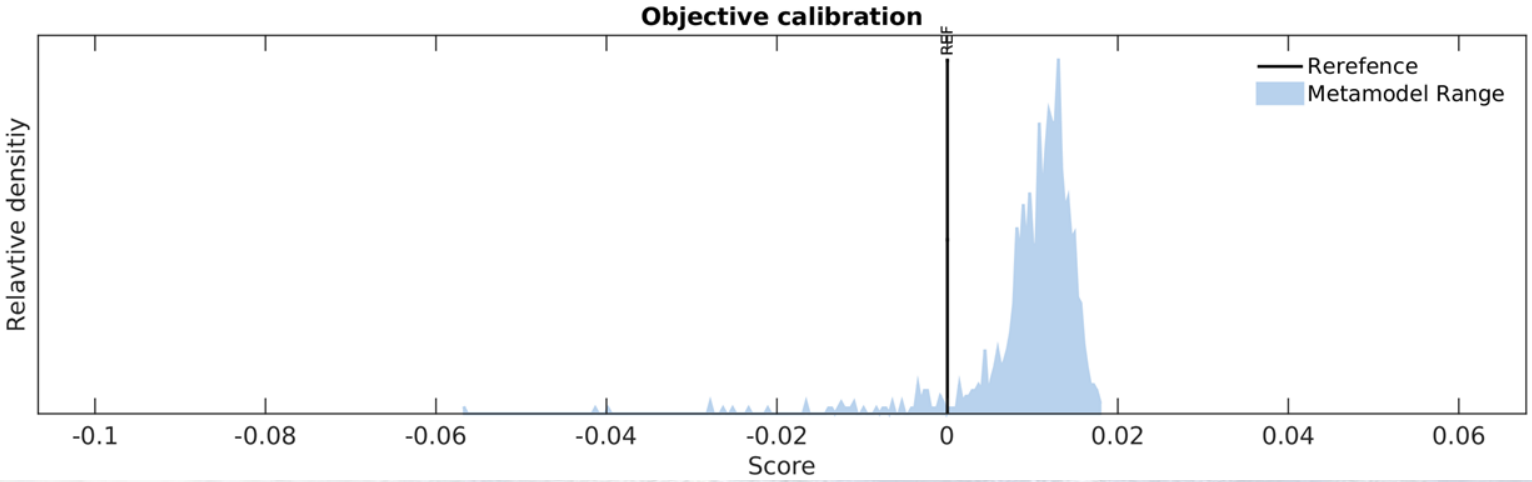
Iteration 3


Objective calibration
REF
Rerefence
Metamodel Range
Relavtive densitiy
-0.14
-0.12
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
Score

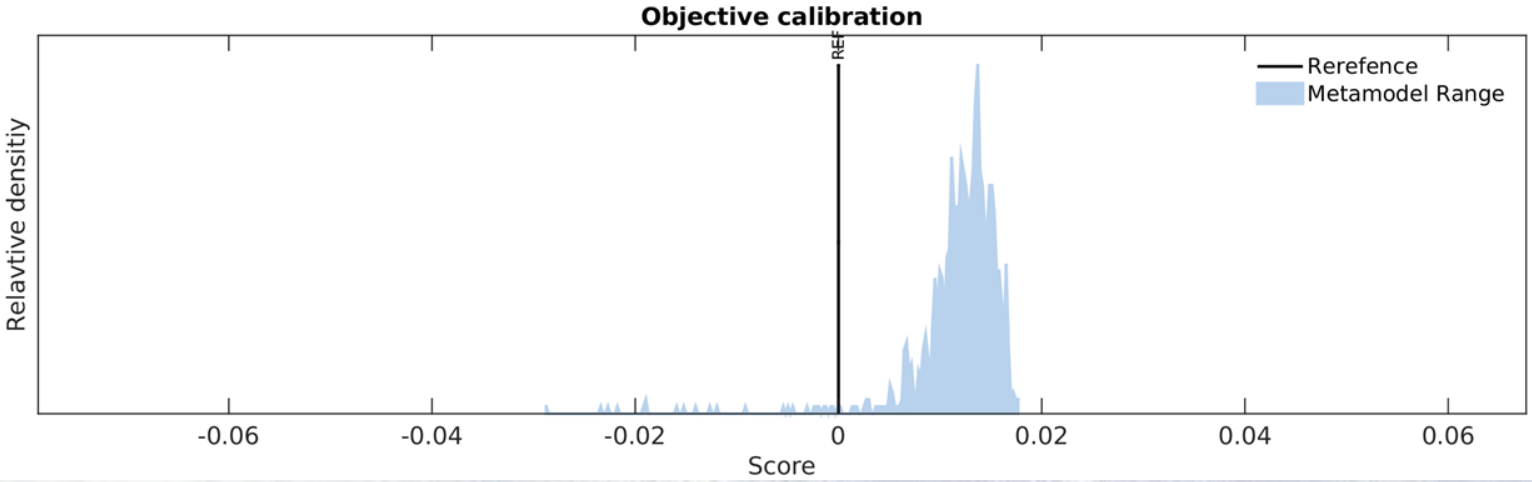
Iteration 4


Objective calibration
Relavtive densitiy
Score
Rerefence
Metamodel Range
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06

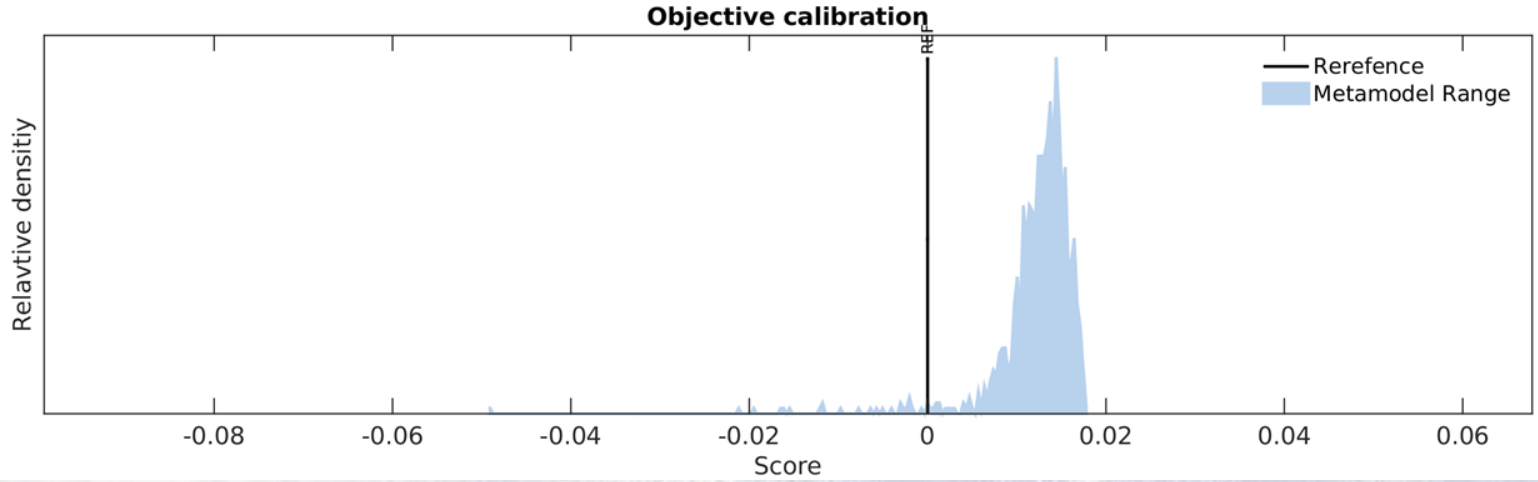
Iteration 5


Objective calibration
REF
Rerefence
Metamodel Range
Relavtive densitiy
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
Score

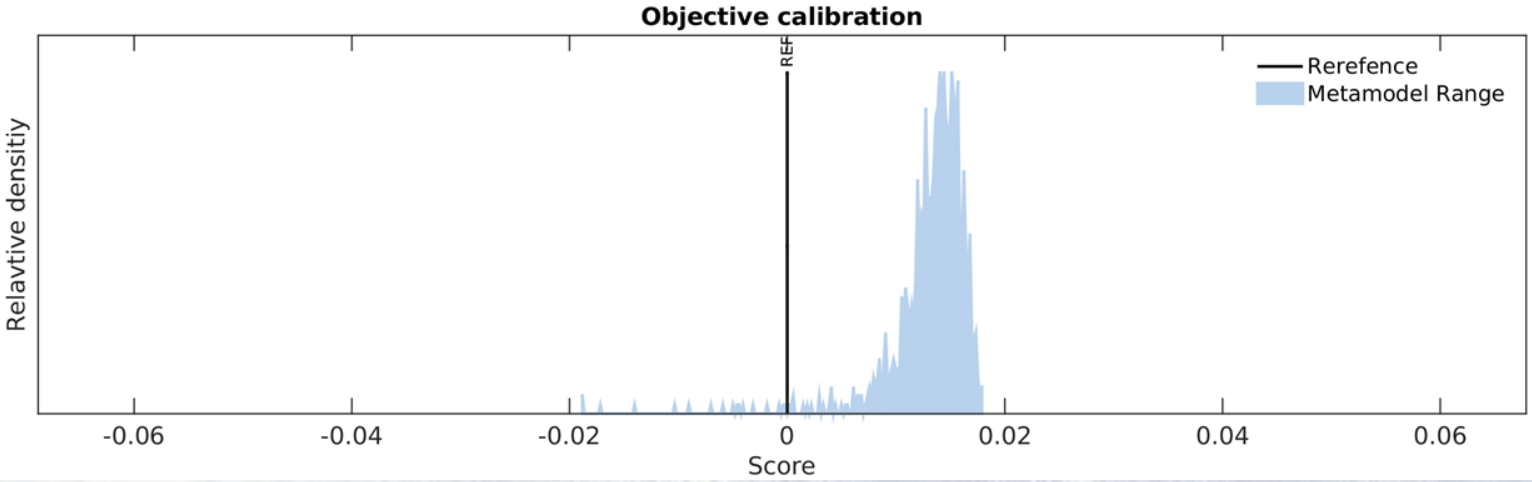
Iteration 6


Objective calibration
REF
Rerefence
Metamodel Range
Relavtive densitiy
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
Score

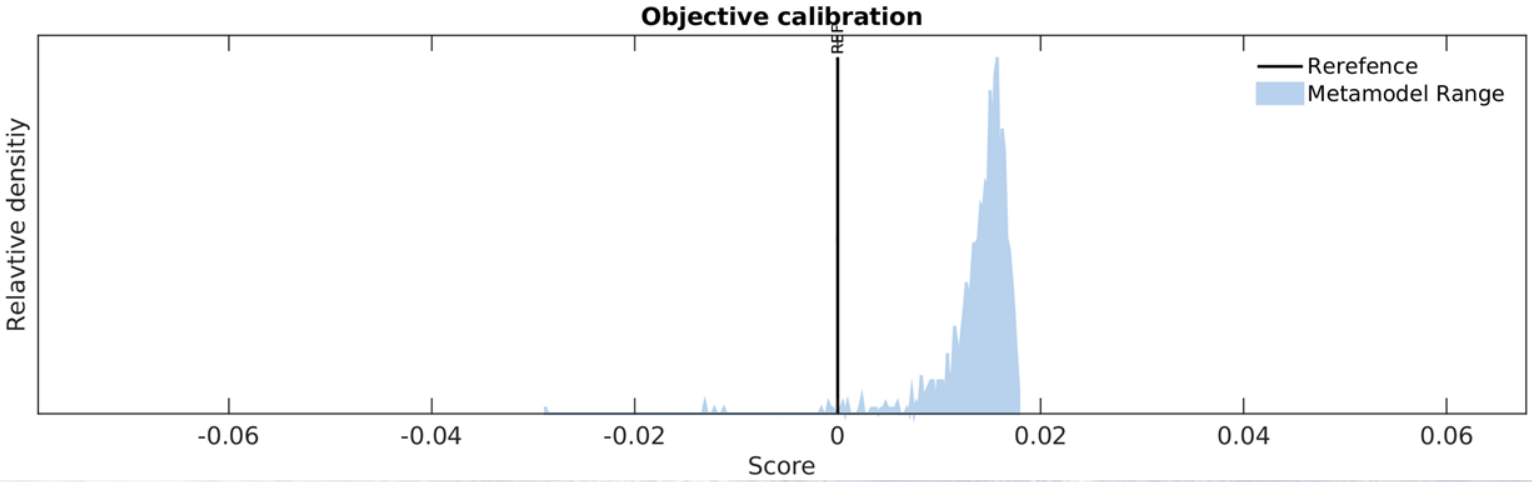
Iteration 7


Objective calibration
REF
Rerefence
Metamodel Range
Relavtive densitiy
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
Score

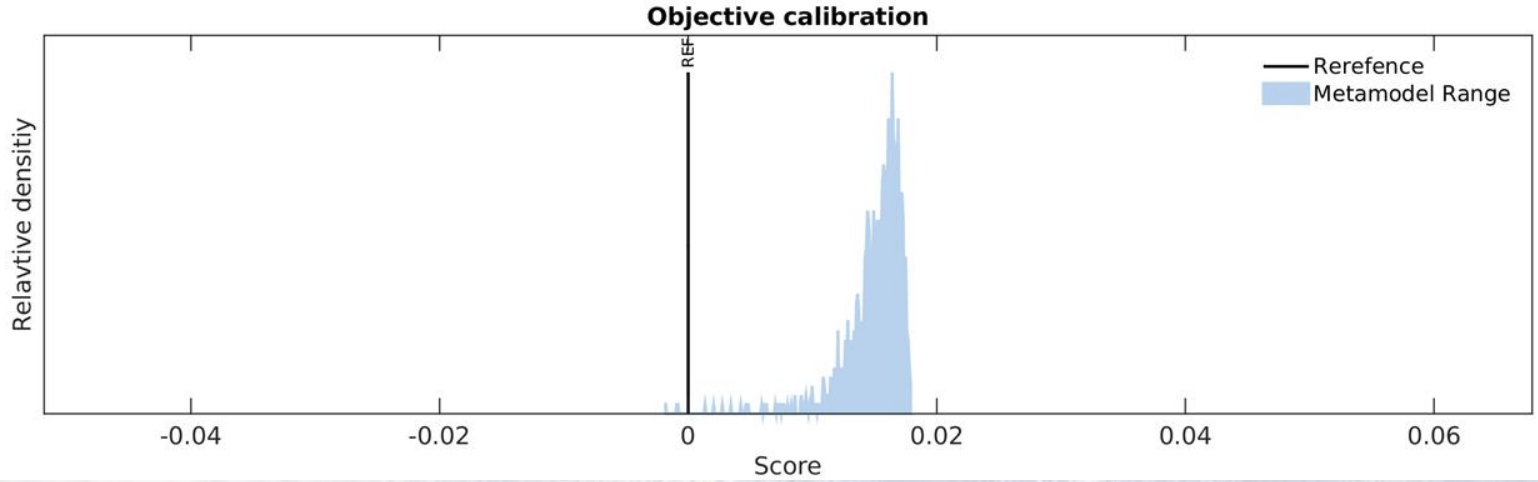
Iteration 8


Objective calibration
REF
Rerefence
Metamodel Range
Relavtive densitiy
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
Score

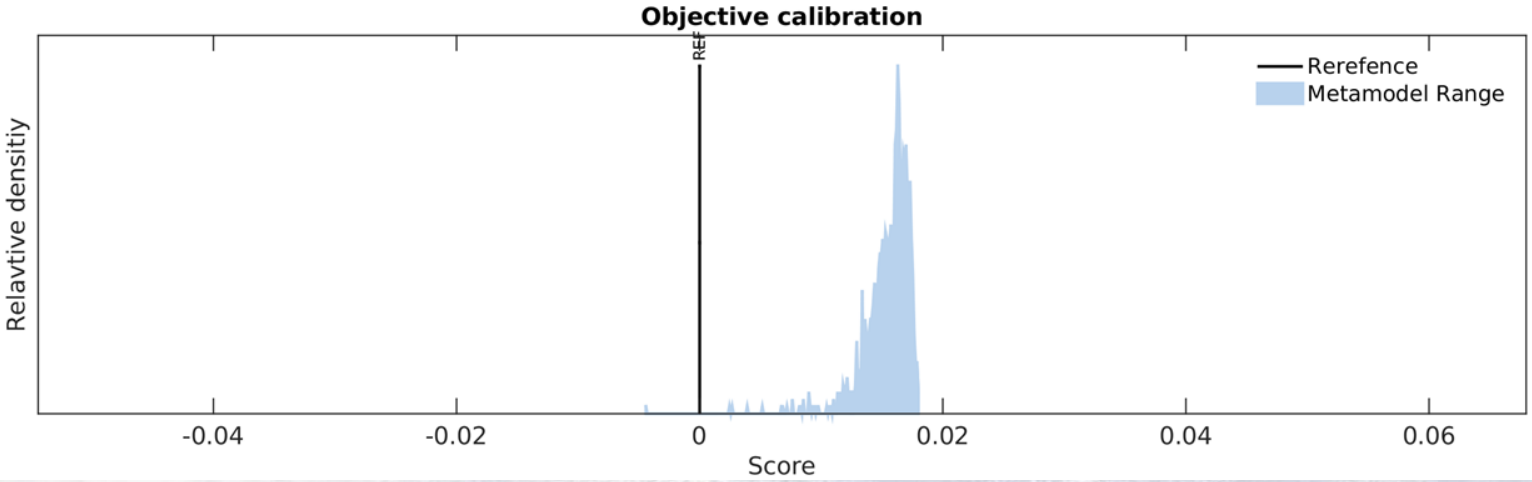
Iteration 9


Objective calibration
REF
Rerefence
Metamodel Range
Relavtive densitiy
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
Score

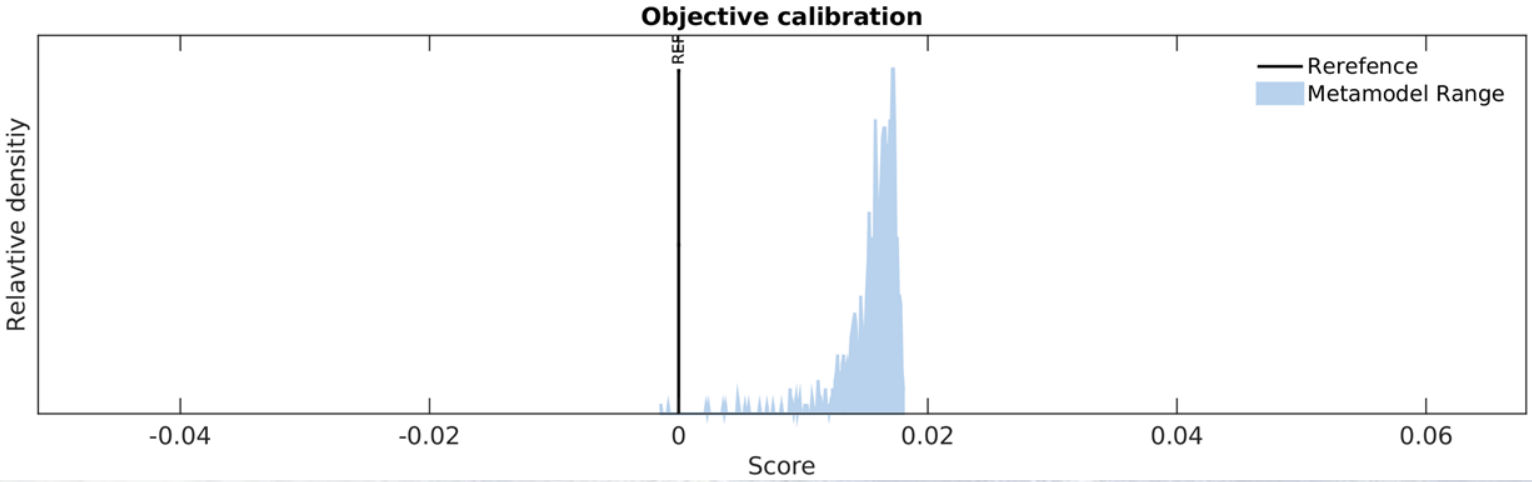
Iteration 10



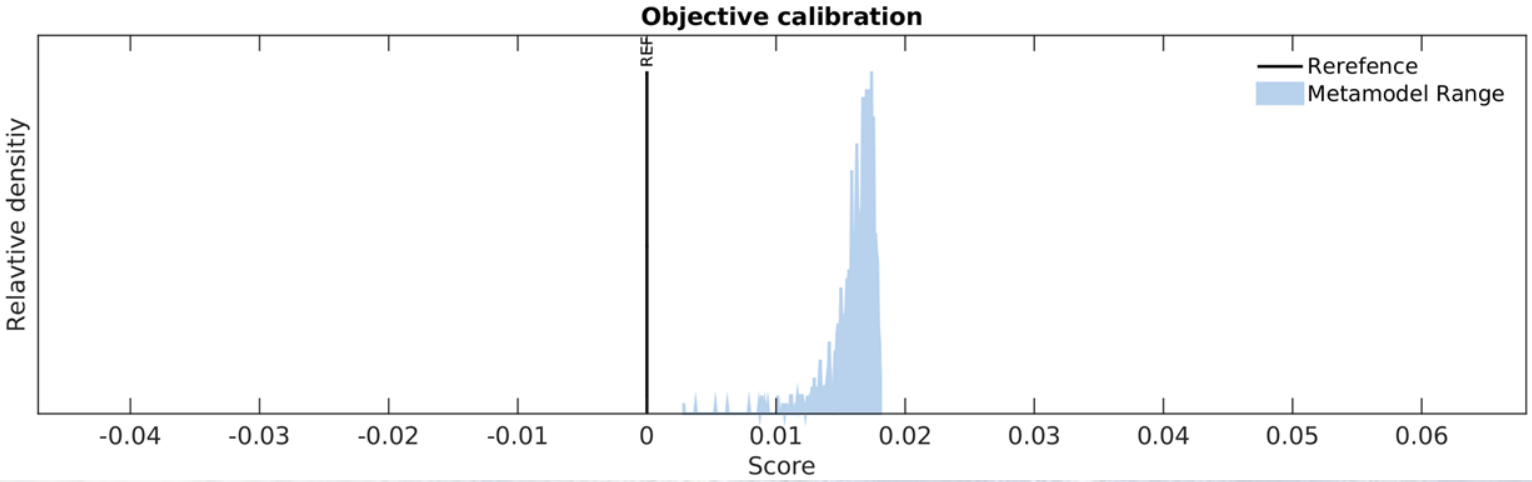
Iteration 11



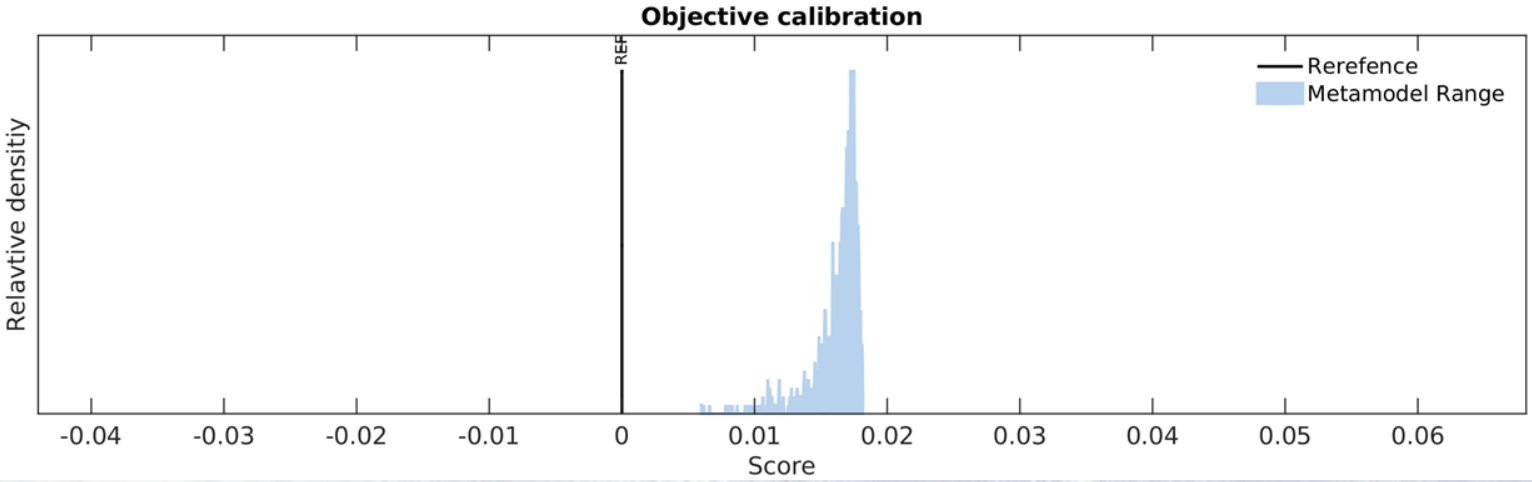
Iteration 12



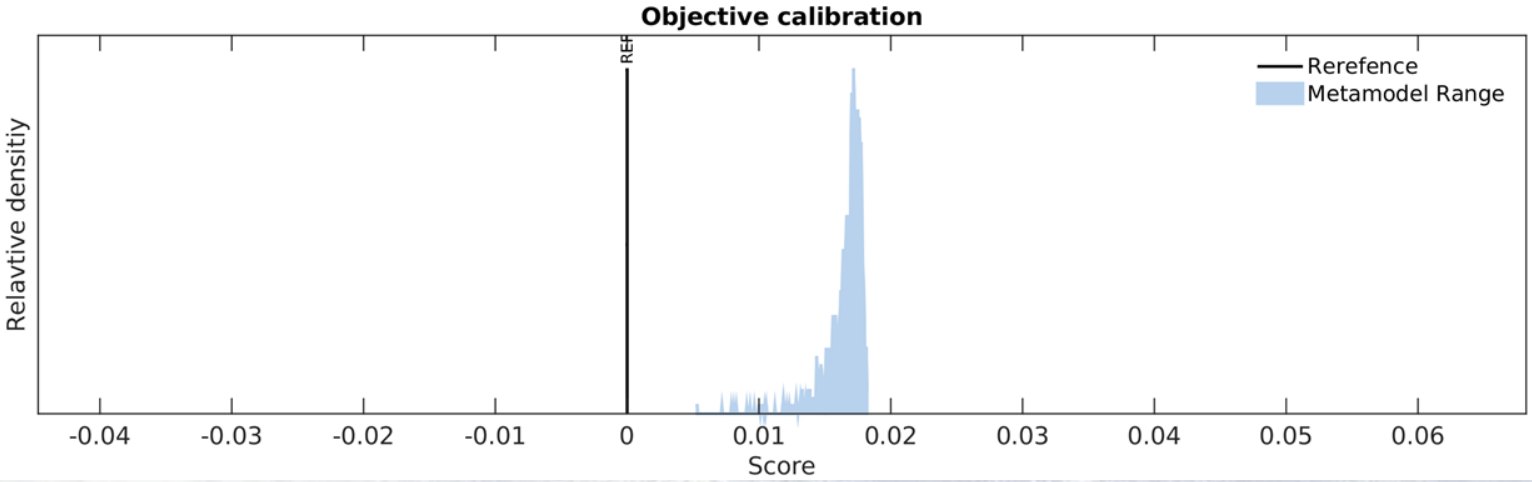
Iteration 13



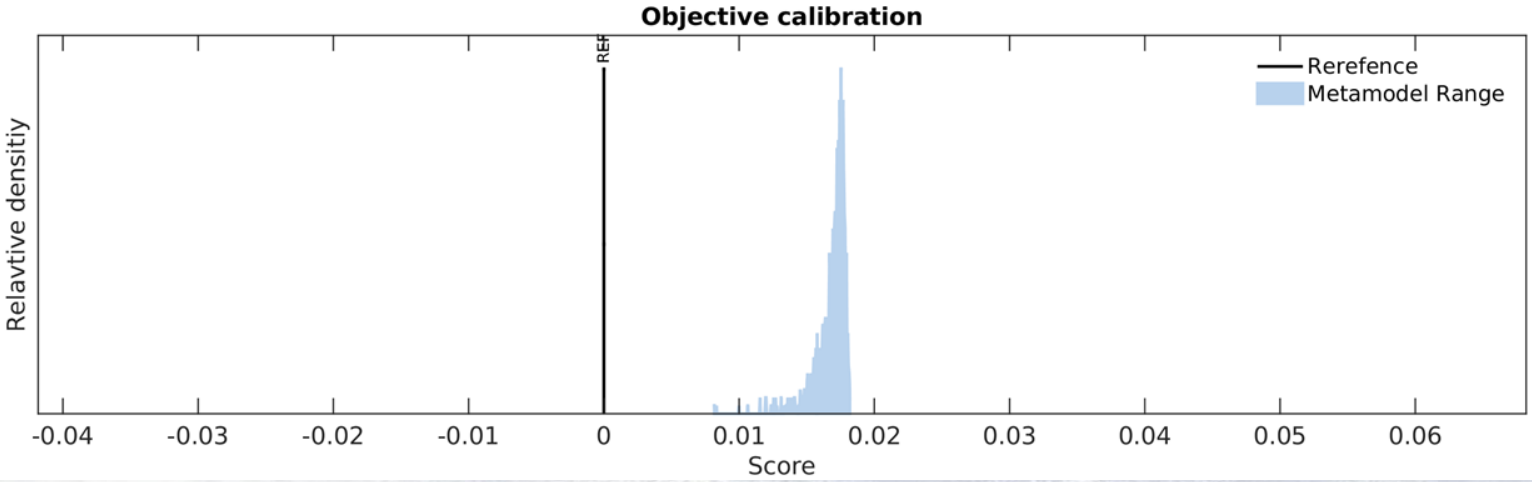
Iteration 14



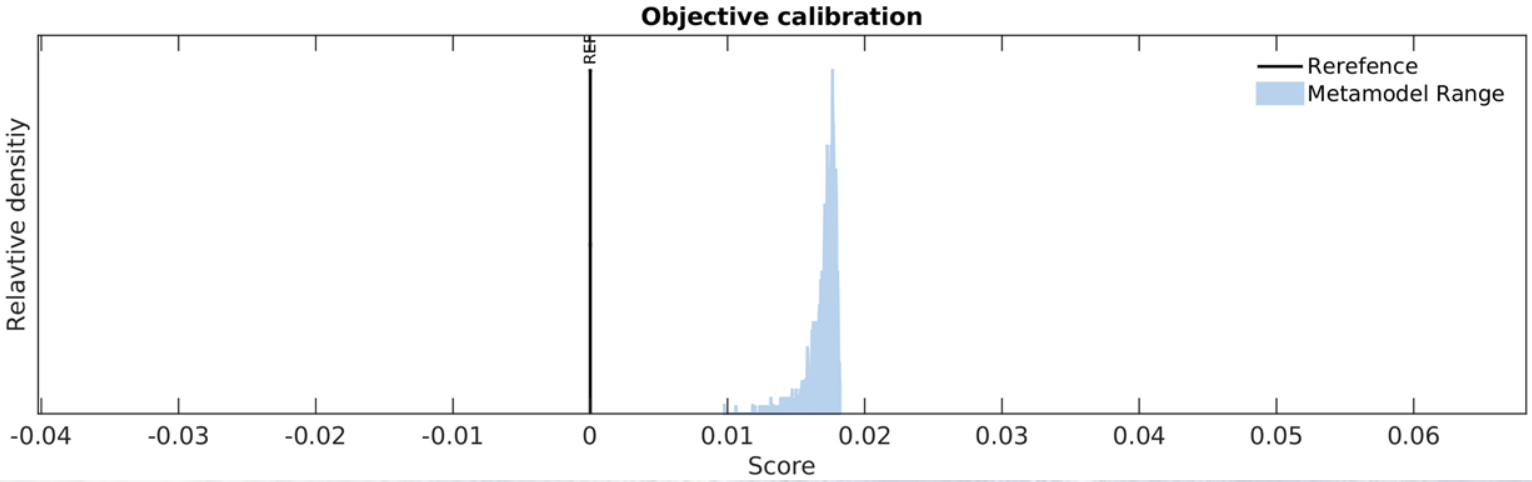
Iteration 15



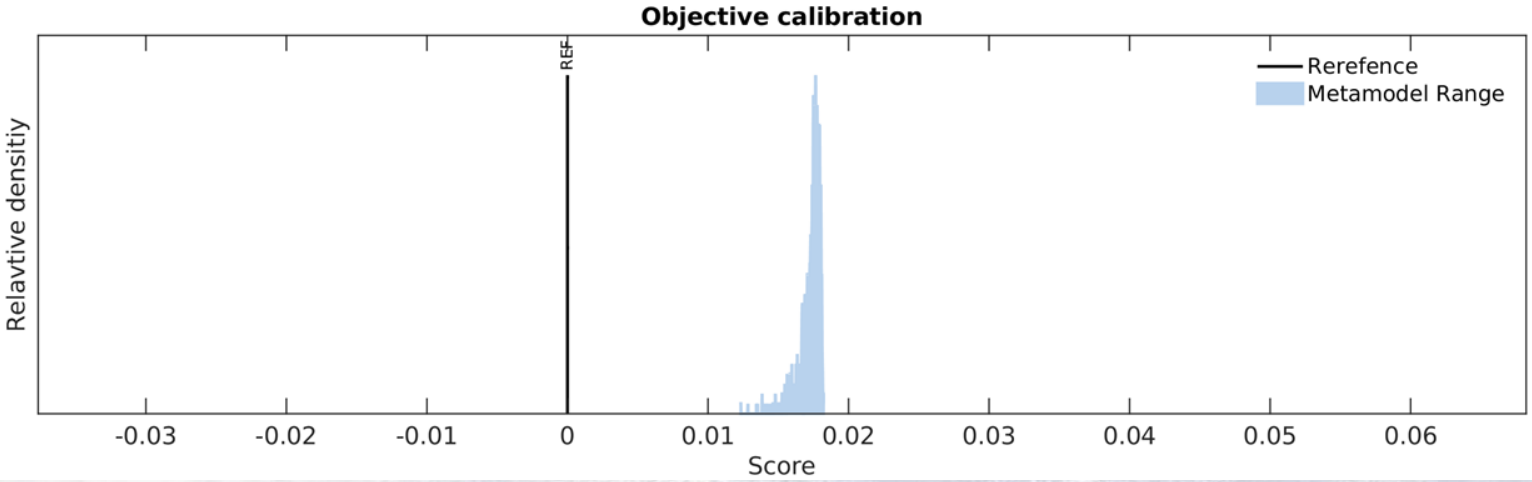
Iteration 16



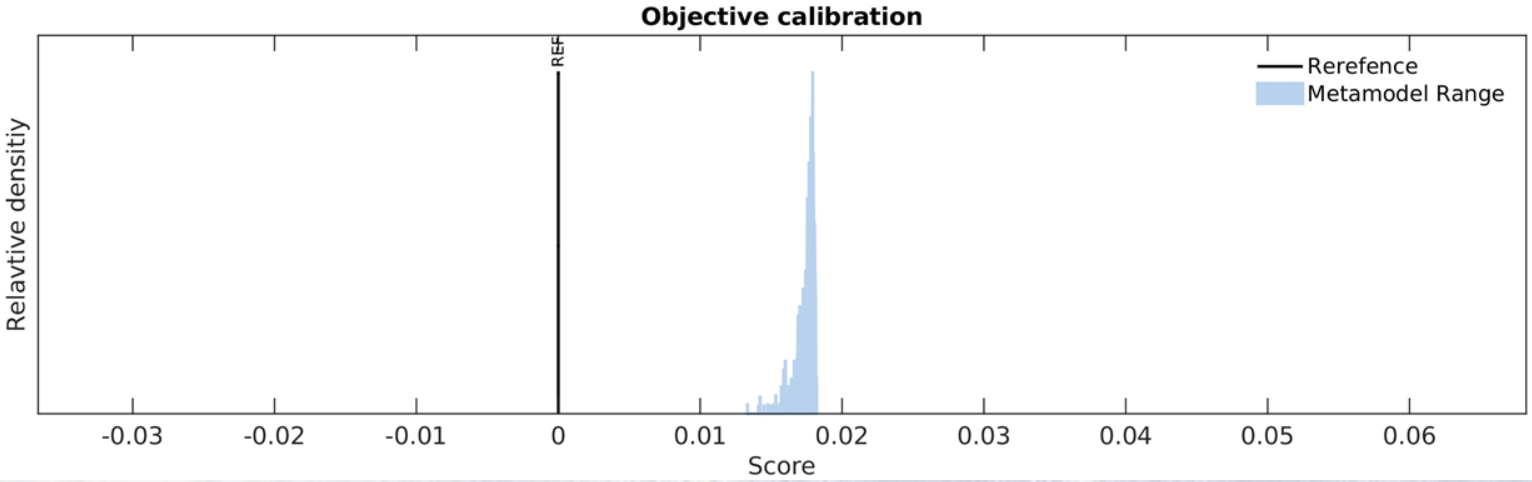
Iteration 17



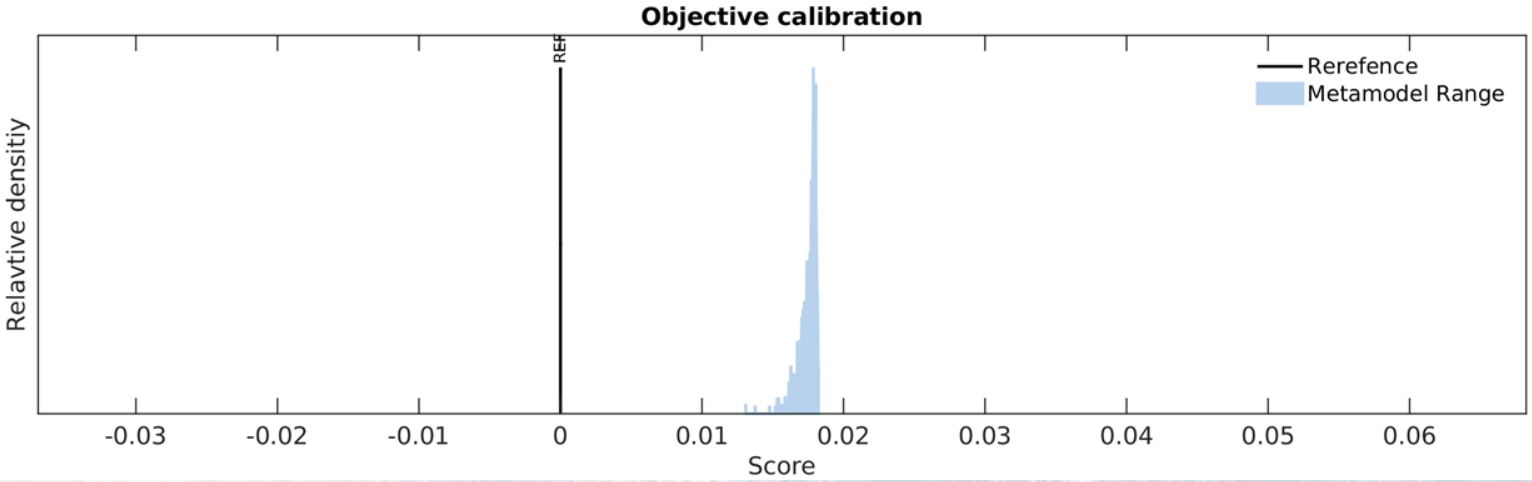
Iteration 18



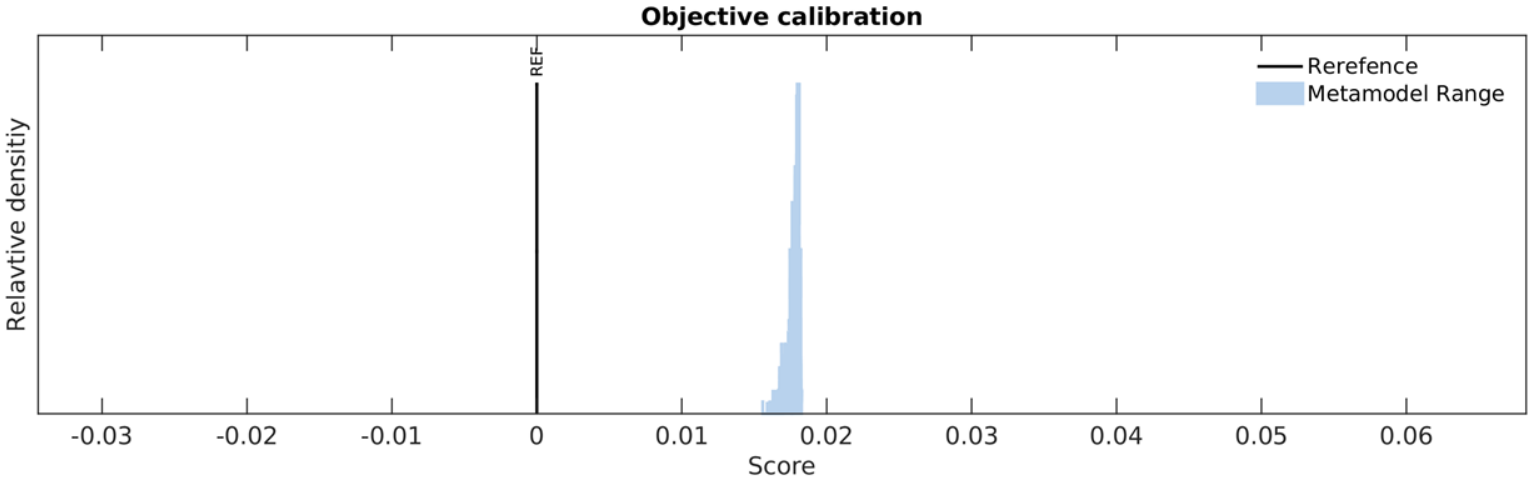
Iteration 19



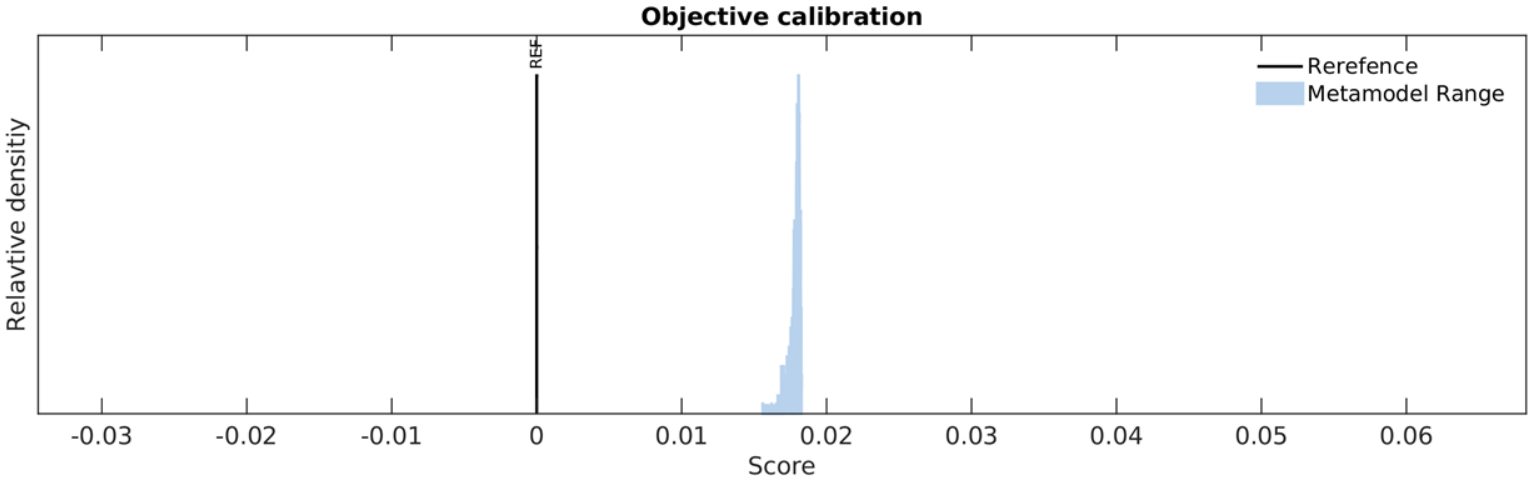
Iteration 20



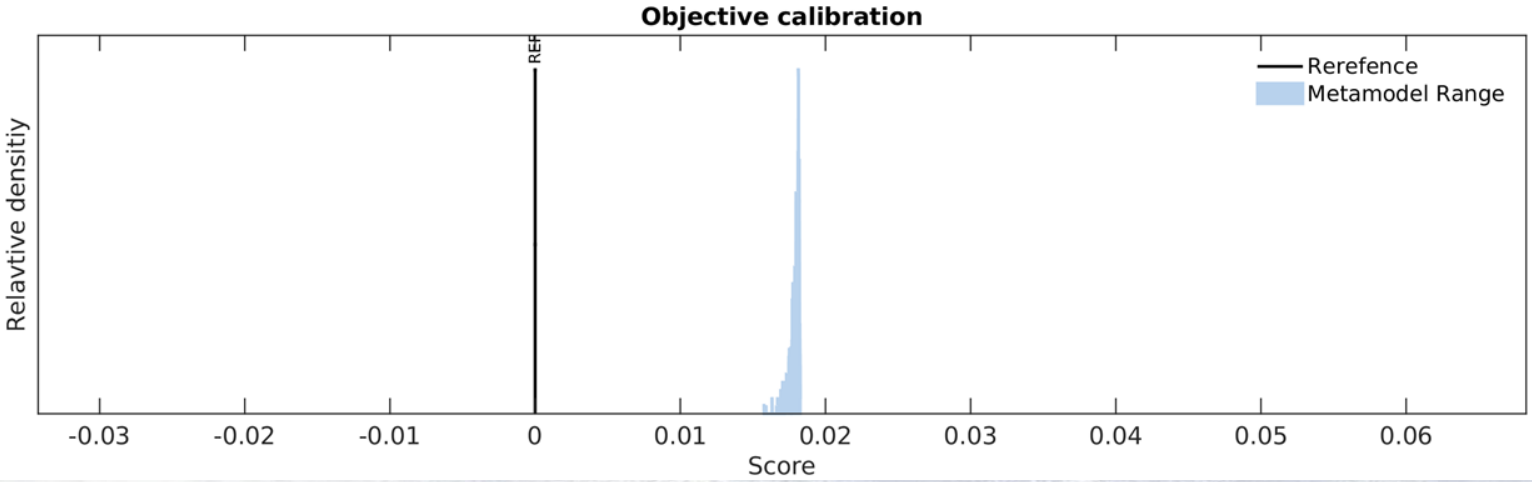
Iteration 21



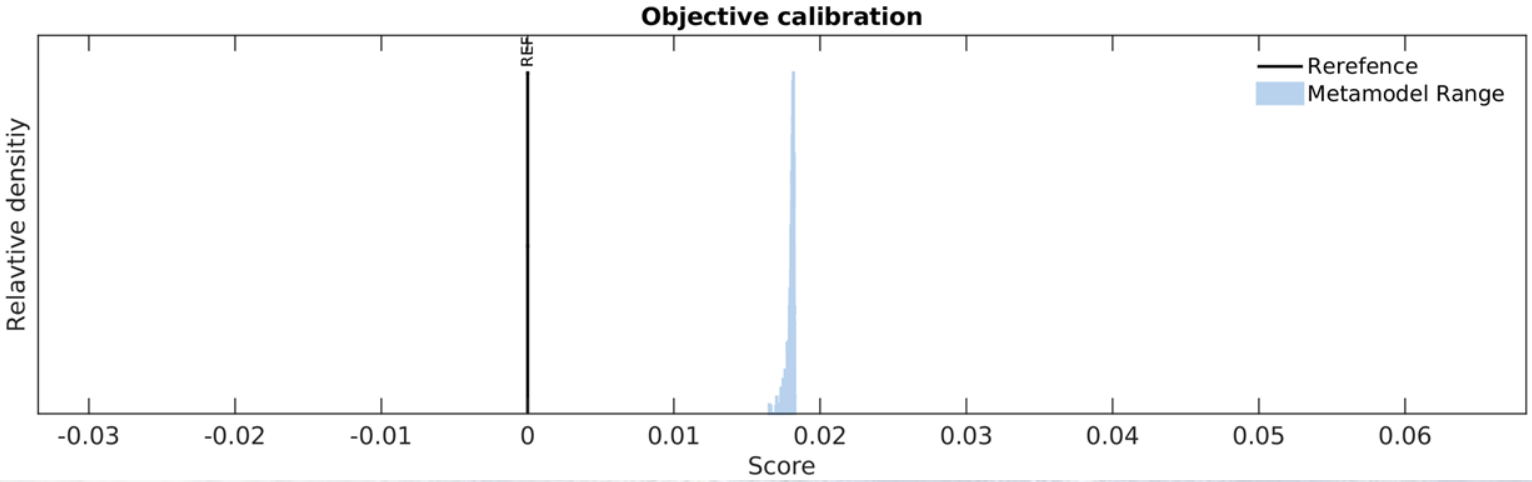
Iteration 22



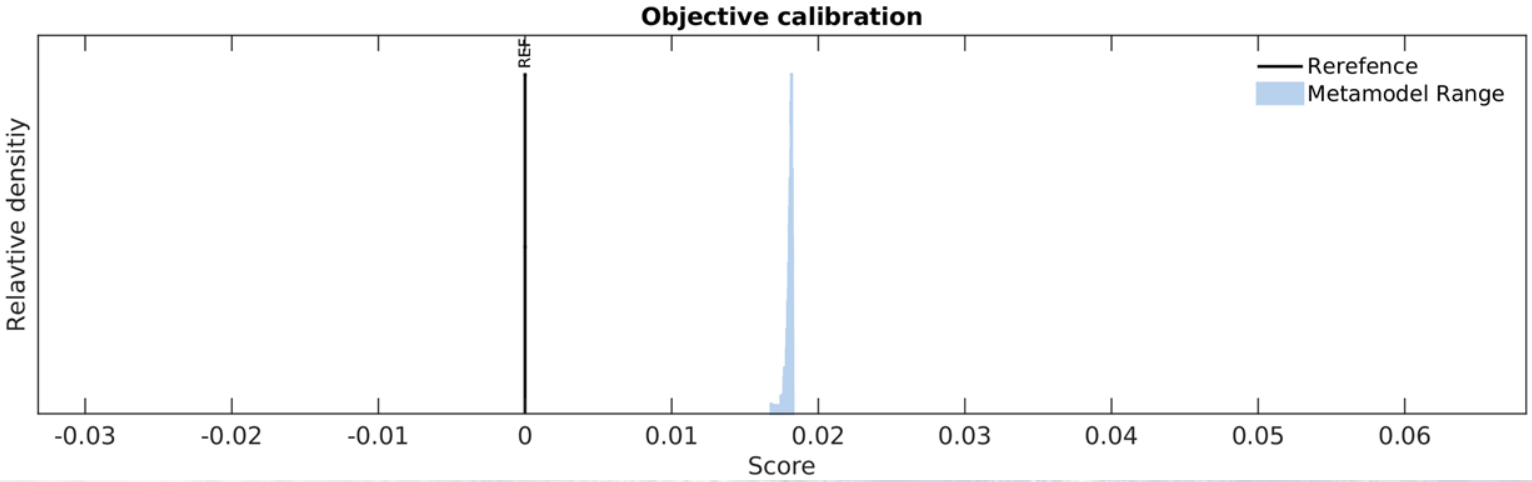
Iteration 23



Iteration 24



Iteration 25



Outline

1. **Overview: from CALMO-stage1 to CALMO-stage2**
2. **Adaptations to the Meta-Model**
   - Option not to average Tmax/Tmin over regions
   - Meta-Model predicts profiles characteristics
   - Defining new regions
   - Performance scores
     - RMSE-type score
     - COSI-type score
   - Logarithmic transformation for some of the parameters
   - Convergence to the optimal parameters combination
3. **Calibration results**
4. **Summary**

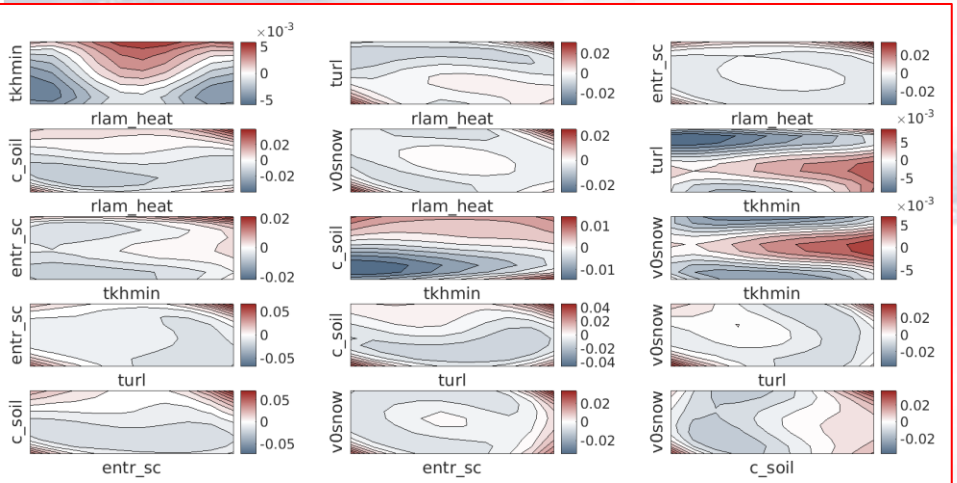
Calibration results

The calibration was performed using 4 different methods:

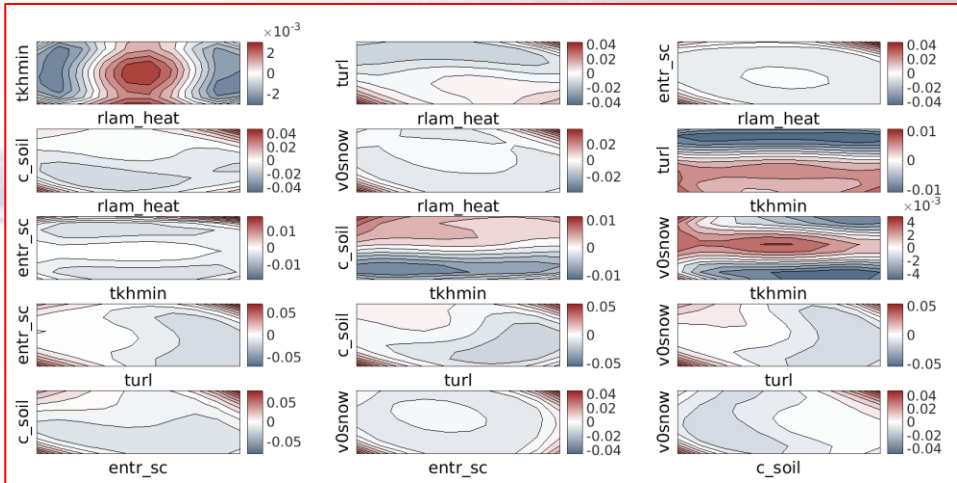
1. **Averaging Tmax and Tmin over regions, using RMSE-type score**
2. **Not averaging Tmax and Tmin over regions, using RMSE-type score**
3. **Averaging Tmax and Tmin over regions, using or the COSI score**
4. **Not averaging Tmax and Tmin over regions, using the COSI score**

Calibration results

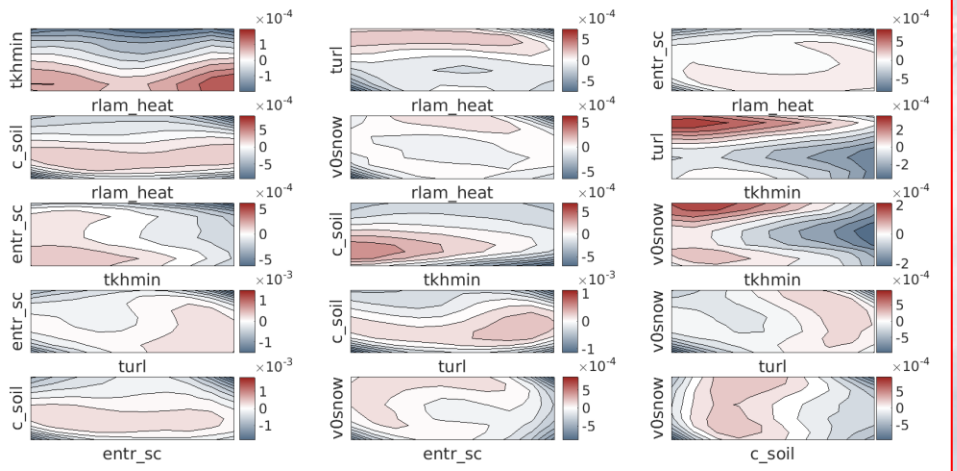
1. Averaging Tmax/Tmin over regs, RMSE-type score



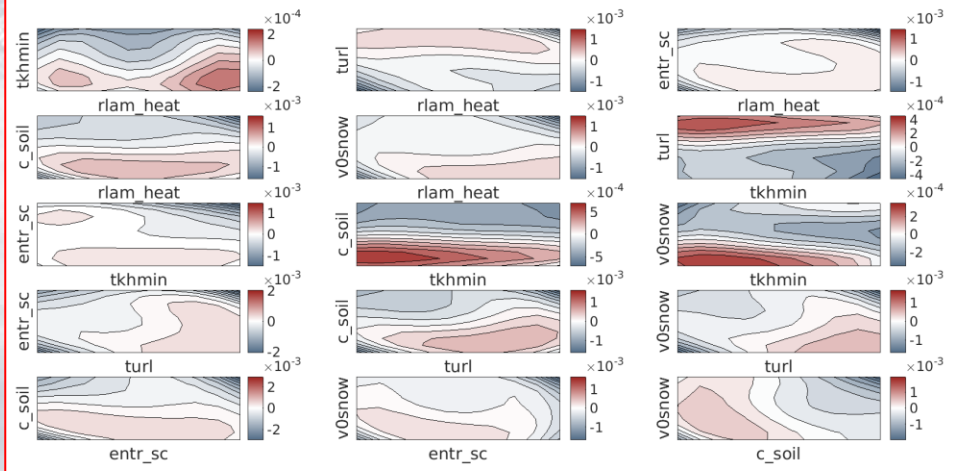
2. Not averaging Tmax/Tmin over regs, RMSE-type score



3. Averaging Tmax/Tmin over regs, COSI-type score

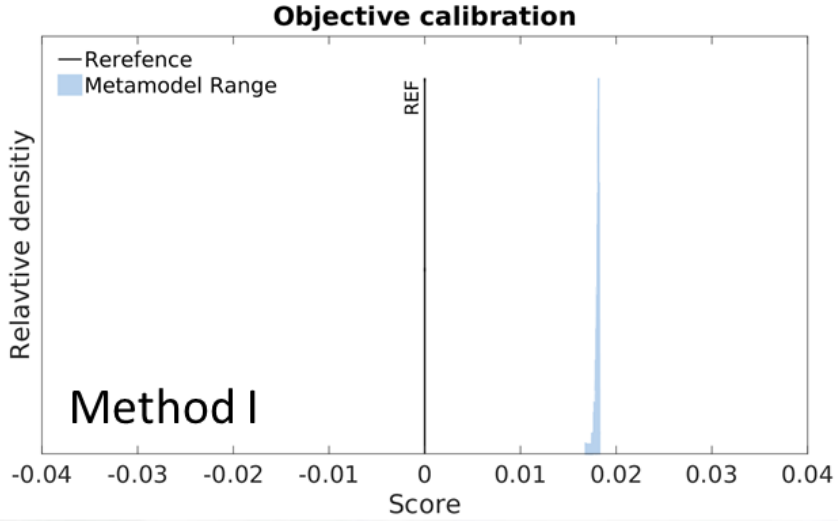


4. Not averaging Tmax/Tmin over regs, COSI-type score

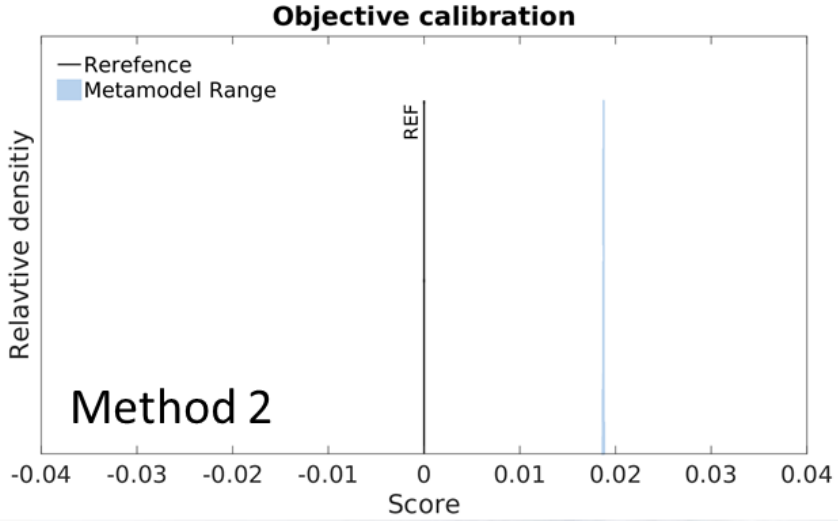


Calibration results

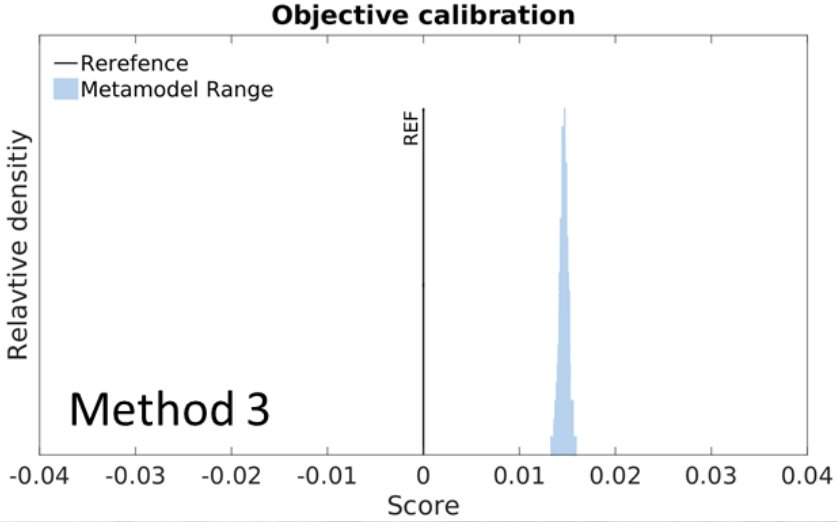
1. Averaging Tmax/Tmin over regs, RMSE-type score



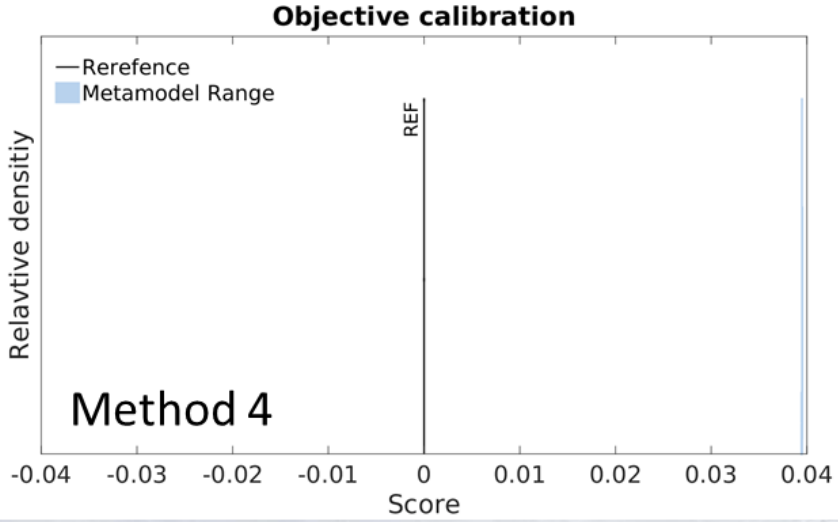
2. Not averaging Tmax/Tmin over regs, RMSE-type score



3. Averaging Tmax/Tmin over regs, COSI-type score



4. Not averaging Tmax/Tmin over regs, COSI-type score



Calibration results

Optimal parameters combination:

	METHOD I	METHOD II	METHOD III	METHOD IV
	rlam_heat=0.763 tkhmin=0.209 tur_len=312.7 entr_sc=0.000101 csoil=0.626 v0snow=17.9	rlam_heat=1.105 tkhmin=0.390 tur_len=475.6 entr_sc=0.000077 csoil=0.761 v0snow=18.2	**rlam_heat=0.740** **tkhmin=0.176** **tur_len=368.8** **entr_sc=0.000114** **csoil=0.663** **v0snow=17.8**	rlam_heat=1.240 tkhmin=0.233 tur_len=363.9 entr_sc=0.000267 csoil=0.492 v0snow=12.1
METHOD I	1.828 %	1.557 %	1.801 %	1.329 %
METHOD II	1.647 %	1.880 %	1.685 %	1.556 %
METHOD III	1.481 %	1.217 %	1.587 %	0.980 %
METHOD IV	2.980 %	2.966 %	2.916 %	3.951 %
Average score:	1.984 %	1.905 %	**1.997 %**	1.954 %

1. **Averaging Tmax and Tmin over regions, using RMSE-type score**
2. **Not averaging Tmax and Tmin over regions, using RMSE-type score**
3. **Averaging Tmax and Tmin over regions, using or the COSI score**
4. **Not averaging Tmax and Tmin over regions, using the COSI score**

Outline

1. **Overview: from CALMO-stage1 to CALMO-stage2**
2. **Adaptations to the Meta-Model**
   - Option not to average Tmax/Tmin over regions
   - Meta-Model predicts profiles characteristics
   - Defining new regions
   - Performance scores
     - RMSE-type score
     - COSI-type score
   - Logarithmic transformation for some of the parameters
   - Convergence to the optimal parameters combination
3. **Calibration results**
4. **Summary**

Summary

For COSMO-2.2km, try the following parameters combination:

- **rlam_heat=0.740 instead of the default 1.0**
- **tkhmin=0.176 instead of the default 0.4**
- **tur_len=368.8 instead of the default 150**
- **entr_sc=0.000114 instead of the default 0.003**
- **csoil=0.663 instead of the default 1.0**
- **v0snow=17.8 instead of the default 20**

Thank you !