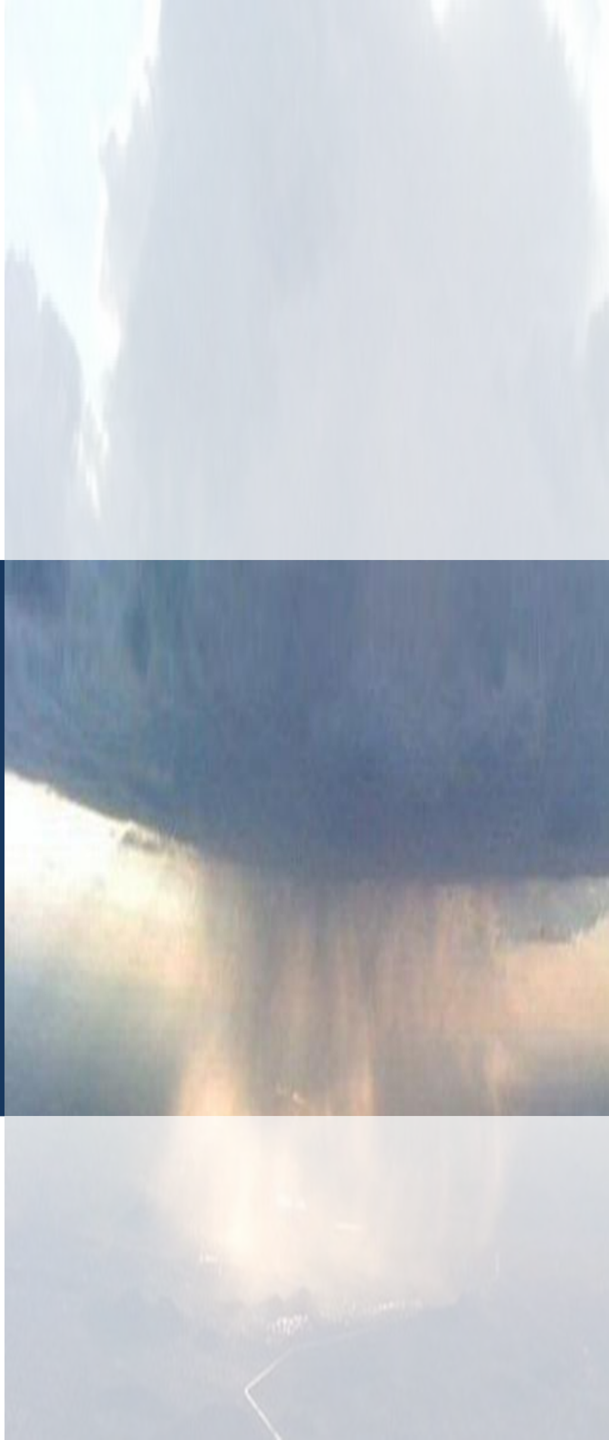
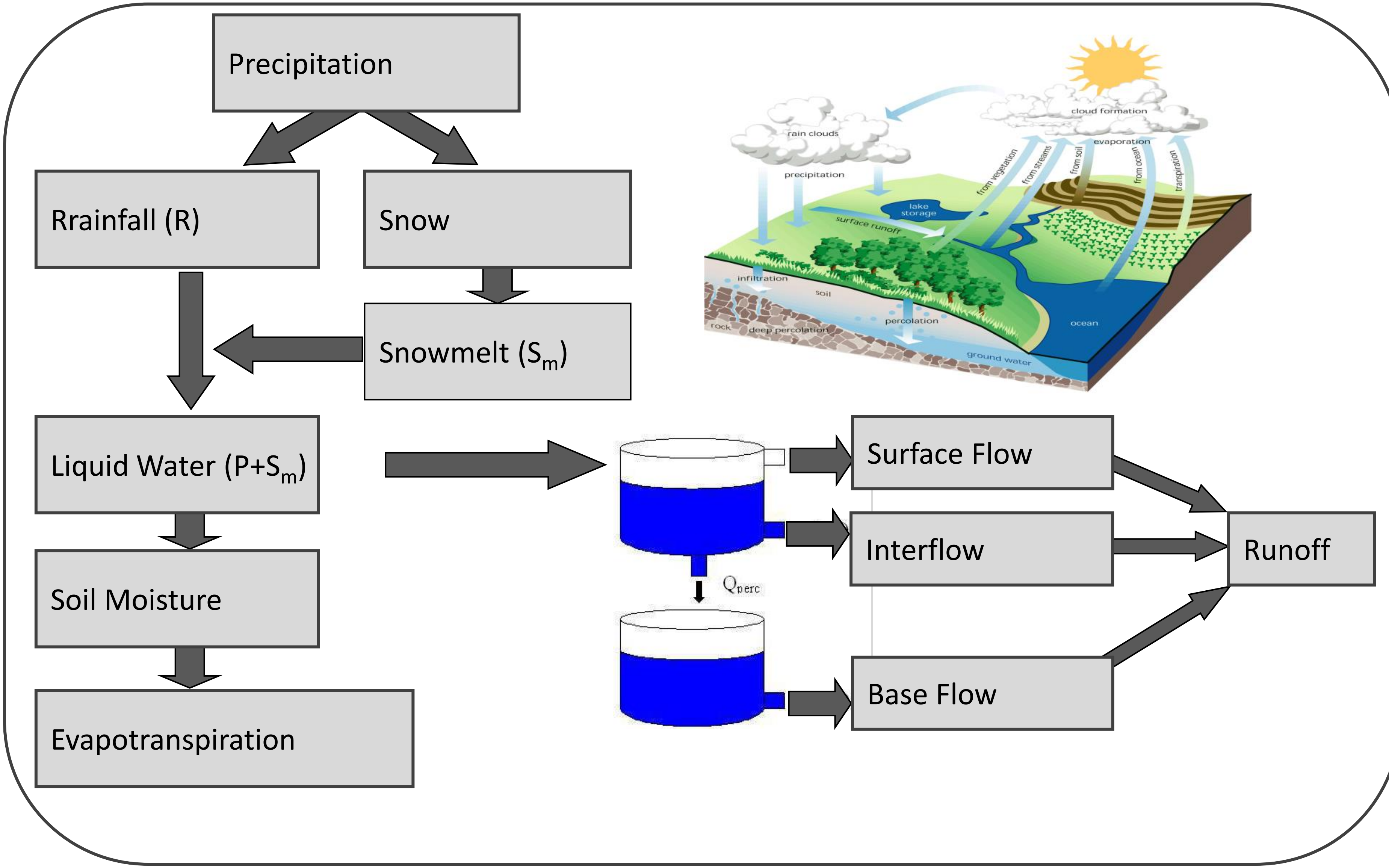


Integrated Water Cycle Analysis II

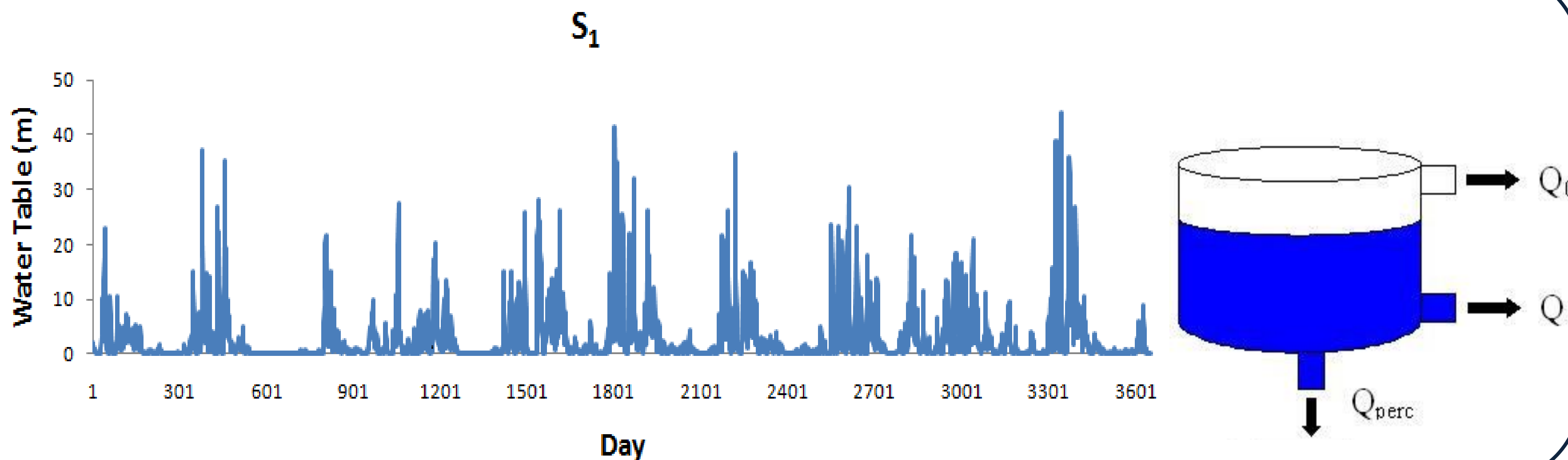
Amir AghaKouchak
University of California, Irvine

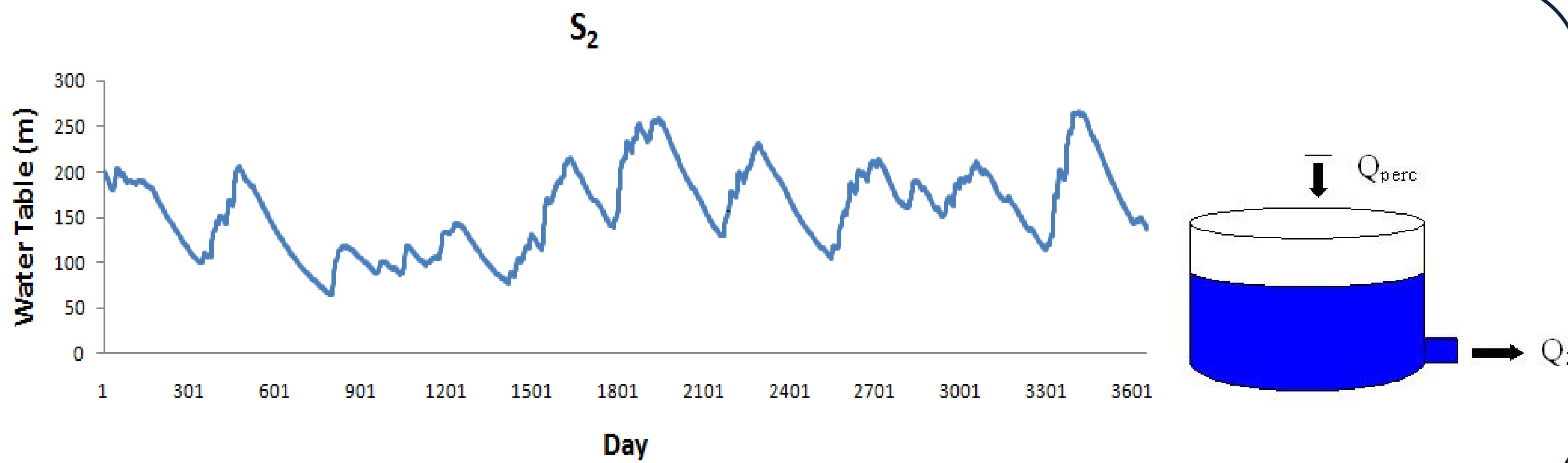
2nd Workshop on Water Resources in Developing Countries: Planning and Management in a Climate Change Scenario, 6-17 May 2013, Trieste, Italy.

Model Structure (Review)

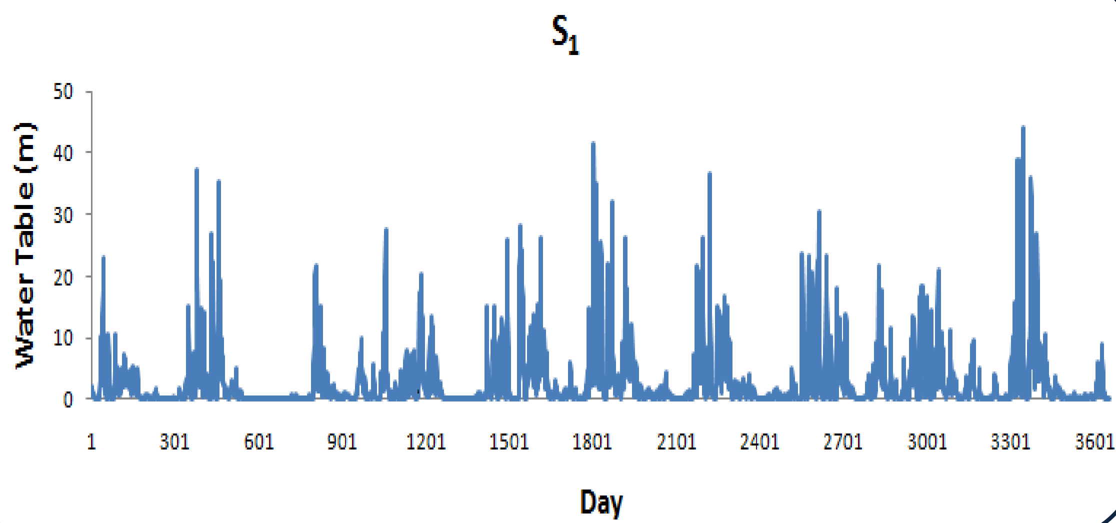


Reservoir Concept

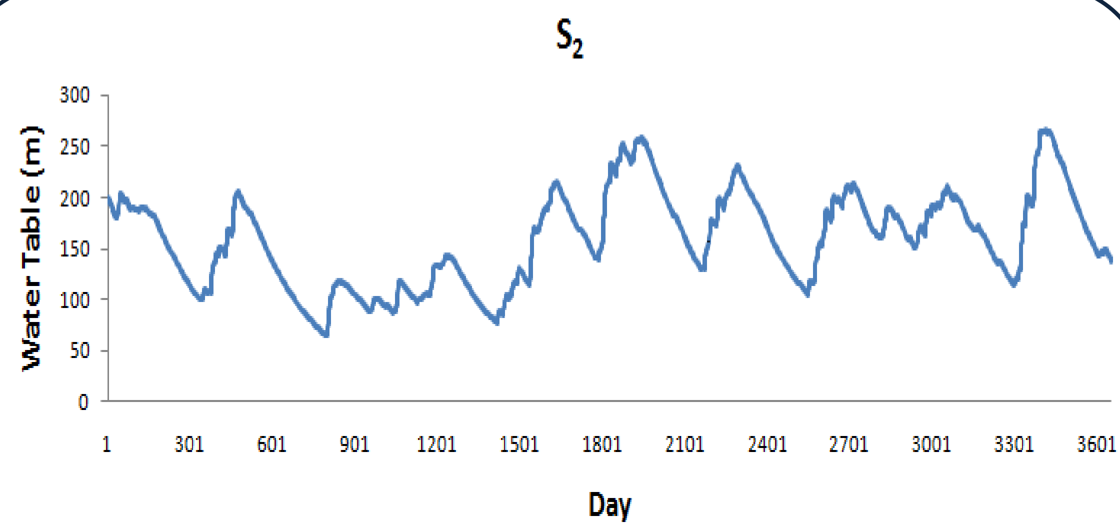




Reservoir Concept



$$Q_0 = K_0 .(S_1\text{-}L). A$$
$$Q_1 = K_1 . S_1 . A$$
$$Q_2 = K_2 . S_2 . A$$



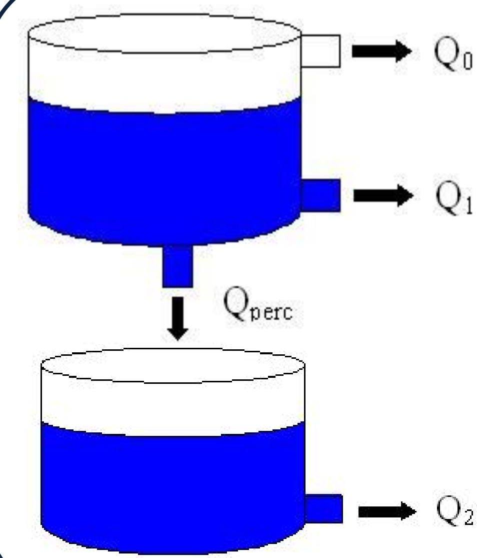
$$K_0 > K_1 > K_2$$

Runoff Response

$$Q = Q_0 + Q_1 + Q_2$$

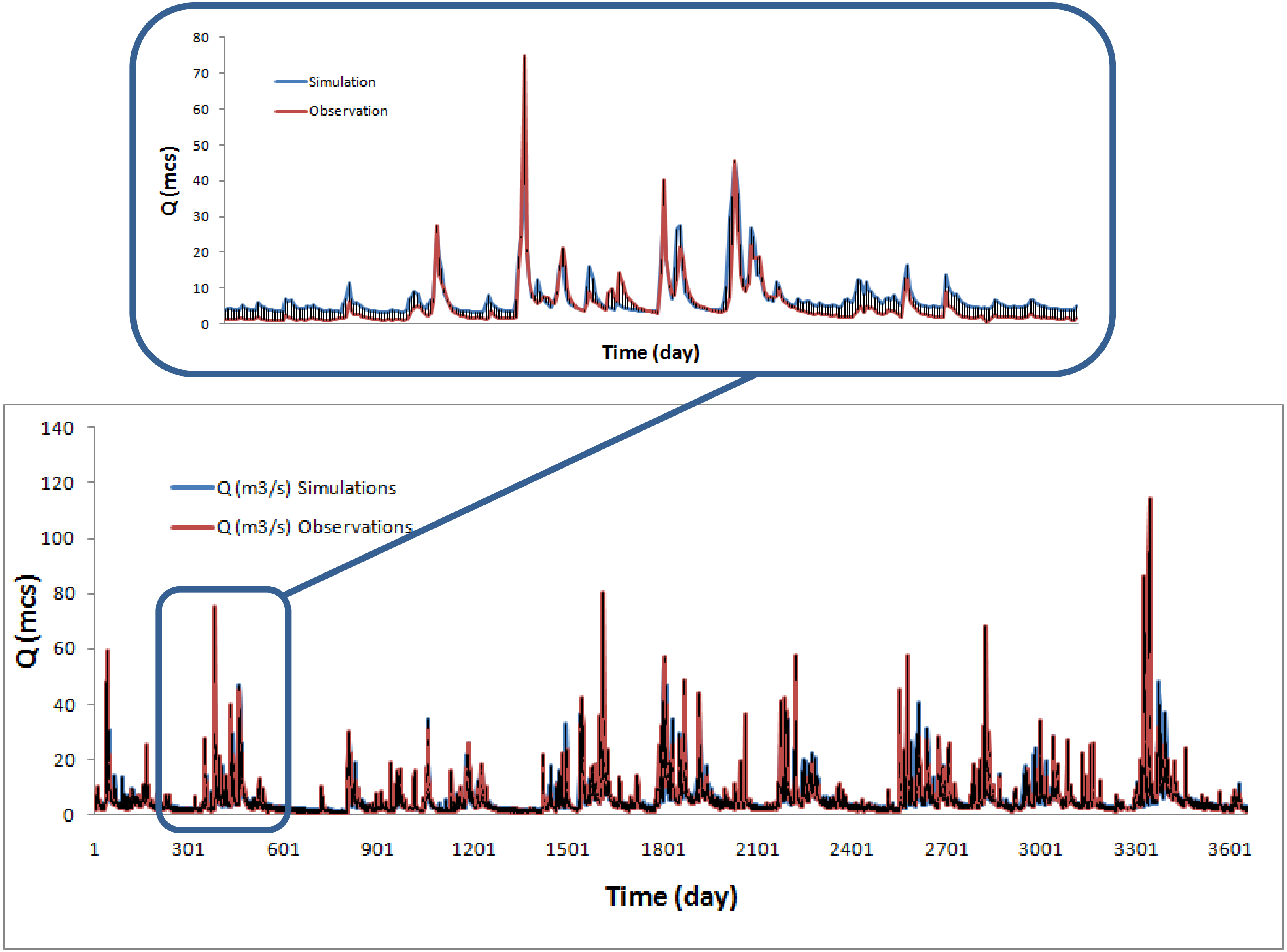
=MAX(0,K31-F9)*F8+K31*F10+L31*F11

$K_0 (S_1 - L)$ — $K_1 (S_1)$ — $K_2 (S_2)$



Temp. (C)	Preci. (mm)	Snow (mm)	Liquid Water	Soil Moisture	DQ (mm/day) OR P_{eff}	Potential E. (PE_a)	E_a (mm/day)	S_1	S_2	Total Q (Q_t) (mm/day)	Q (m^3/s) Simulations	Q (m^3/s) Observations
		25		100.0				2.000	200.000	1.065		
-1.5	0.4	25.4	0	99.8	0.000	0.161	0.153	1.291	199.644	0.969	4.600	4.5
-0.8	10.5	35.9	0	99.7	0.000	0.164	0.156	0.833	199.133	0.907	4.303	11
-2.8	0.9	36.8	0	99.5	0.000	0.155	0.147	0.538	198.521	0.865	4.106	6.6
-3.7	4.4	41.2	0	99.4	0.000	0.150	0.142	0.347	197.847	0.837	3.973	5
-6.1	0.6	41.8	0	99.3	0.000	0.139	0.131	0.224	197.133	0.818	3.883	4.1
-3	0	41.8	0	99.1	0.000	0.154	0.145	0.145	196.394	0.805	3.819	3.5
-0.7	4.4	46.2	0	99.0	0.000	0.165	0.155	0.093	195.640	0.795	3.772	3.2
1.8	3.1	40.8	8.5	107.0	0.336	0.177	0.167	0.396	194.879	0.832	3.948	3.2
0.6	1.7	39	3.5	110.1	0.211	0.171	0.171	0.467	194.187	0.838	3.979	5
1.8	3.6	33.6	9	118.3	0.633	0.177	0.177	0.934	193.514	0.898	4.259	7.9

Runoff Response



Validation Criteria

Root Mean Square Error

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(Q_s - Q_o)^2}{n}}$$

Q_s=simulated discharge

Q_o=observed discharge

Ideal RMSE= 0

Bias

$$Bias = \frac{\sum_{i=1}^{n} Q_s}{\sum_{i=1}^{n} Q_o}$$

Q_s=simulated discharge

Q_o=observed discharge

Ideal Bias= 1

Validation Criteria

Correlation Coefficient

Ideal R_p= 1

R_p= -1 Negatively correlated

R_p= 0 Not correlated

R_p= 1 Correlated

$$R_P = \frac{\sum_{i=1}^{n}(Q_o^i - \overline{Q}_o).\sum_{i=1}^{n}(Q_s^i - \overline{Q}_s)}{\sqrt{\sum_{i=1}^{n}(Q_o^i - \overline{Q}_o)^2}.\sqrt{\sum_{i=1}^{n}(Q_s^i - \overline{Q}_s)^2}}$$

where:

R_P	Pearson correlation coefficient [-]
$\bar{O}_s$	mean simulated discharge $[L^3T^{-1}]$

Nash-Sutcliff Coefficient

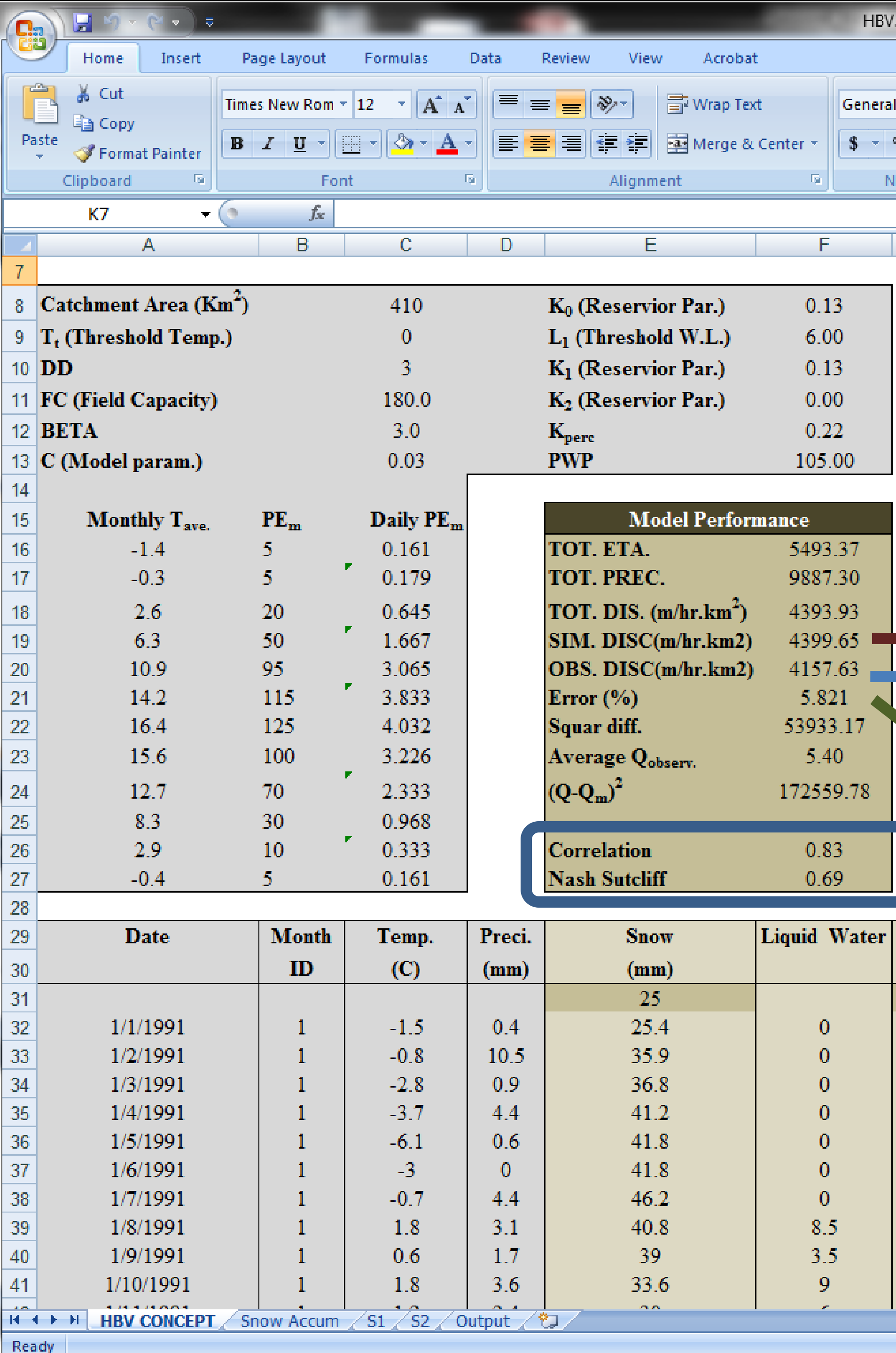
Ideal R_{NS}= 1

Negative R_{NS} means that the mean of observations is a better predictor than the model.

$$R_{NS} = 1 - \frac{\sum_{t=1}^{n}(Q_s^t - Q_o^t)^2}{\sum_{t=1}^{n}(Q_o^t - \overline{Q}_o)^2}$$

where:

R_{NS}	Nash-Sutcliffe coefficient [-]
Q_s	simulated discharge $[L^3T^{-1}]$
Q_o	observed discharge $[L^3T^{-1}]$
$\bar{O}_o$	mean observed discharge $[L^3T^{-1}]$
n	number of time steps



Catchment Area (Km^2)		410		K_0 (Reservior Par.)	0.13
T_t (Threshold Temp.)		0		L_1 (Threshold W.L.)	6.00
DD		3		K_1 (Reservior Par.)	0.13
FC (Field Capacity)		180.0		K_2 (Reservior Par.)	0.00
BETA		3.0		K_{perc}	0.22
C (Model param.)		0.03		PWP	105.00

Monthly $T_{ave.}$	PE_m	Daily PE_m
-1.4	5	0.161
-0.3	5	0.179
2.6	20	0.645
6.3	50	1.667
10.9	95	3.065
14.2	115	3.833
16.4	125	4.032
15.6	100	3.226
12.7	70	2.333
8.3	30	0.968
2.9	10	0.333
-0.4	5	0.161

Model Performance	
TOT. ETA.	5493.37
TOT. PREC.	9887.30
TOT. DIS. (m/hr.km^2)	4393.93
SIM. DISC(m/hr.km2)	4399.65
OBS. DISC(m/hr.km2)	4157.63
Error (%)	5.821
Squar diff.	53933.17
Average $Q_{observ.}$	5.40
$(Q-Q_m)^2$	172559.78
Correlation	0.83
Nash Sutcliff	0.69

Date	Month ID	Temp. (C)	Preci. (mm)	Snow (mm)	Liquid Water
				25	
1/1/1991	1	-1.5	0.4	25.4	0
1/2/1991	1	-0.8	10.5	35.9	0
1/3/1991	1	-2.8	0.9	36.8	0
1/4/1991	1	-3.7	4.4	41.2	0
1/5/1991	1	-6.1	0.6	41.8	0
1/6/1991	1	-3	0	41.8	0
1/7/1991	1	-0.7	4.4	46.2	0
1/8/1991	1	1.8	3.1	40.8	8.5
1/9/1991	1	0.6	1.7	39	3.5
1/10/1991	1	1.8	3.6	33.6	9

$$\sum_{i=1}^{n} Q_s$$

$$\sum_{i=1}^{n} Q_o$$

$$Bias = \frac{\sum_{i=1}^{n} Q_s}{\sum_{i=1}^{n} Q_o}$$

Error (%) of total runoff

Nash-Sutcliff Coefficient

$$R_{NS} = 1 - \frac{\sum_{t=1}^{n} (Q_s^t - Q_o^t)^2}{\sum_{t=1}^{n} (Q_o^t - \overline{Q}_o)^2}$$

=(O32-N32)^2

where:

R_{NS}	Nash-Sutcliffe coefficient [-]
Q_s	simulated discharge [L^3T^{-1}]
Q_o	observed discharge [L^3T^{-1}]
$\bar{O}_o$	mean observed discharge [L^3T^{-1}]
n	number of time steps

	Month ID	Temp. (C)	Preci. (mm)	Snow (mm)	Liquid Water	Soil Moisture	DQ (mm/day) OR P_{eff}	Potential E. (PE_a)	E_a (mm/day)	S_1	S_2	Total Q (Q_t) (mm/day)	Q (m^3/s) Simulations	Q (m^3/s) Observations	$(Q-QT)^2$	$(Q-Qm)^2$
31				25		100.0				2.000	200.000	1.065				
32	1	-1.5	0.4	25.4	0	99.8	0.000	0.161	0.153	1.291	199.644	0.969	4.600	4.5	0.010	0.817
33	1	-0.8	10.5	35.9	0	99.7	0.000	0.164	0.156	0.833	199.133	0.907	4.303	11	44.850	31.317
34	1	-2.8	0.9	36.8	0	99.5	0.000	0.155	0.147	0.538	198.521	0.865	4.106	6.6	6.221	1.431
35	1	-3.7	4.4	41.2	0	99.4	0.000	0.150	0.142	0.347	197.847	0.837	3.973	5	1.054	0.163
36	1	-6.1	0.6	41.8	0	99.3	0.000	0.139	0.131	0.224	197.133	0.818	3.883	4.1	0.047	1.700
37	1	-3	0	41.8	0	99.1	0.000	0.154	0.145	0.145	196.394	0.805	3.819	3.5	0.102	3.625
38	1	-0.7	4.4	46.2	0	99.0	0.000	0.165	0.155	0.093	195.640	0.795	3.772	3.2	0.327	4.857
39	1	1.8	3.1	40.8	8.5	105.9	1.413	0.177	0.167	1.473	194.879	0.974	4.624	3.2	2.028	4.857
40	1	0.6	1.7	39	3.5	108.5	0.713	0.171	0.171	1.663	194.426	0.998	4.735	5	0.070	0.163
41	1	1.8	3.6	33.6	9	115.4	1.971	0.177	0.177	3.045	194.018	1.179	5.595	7.9	5.314	6.231

Nash-Sutcliff Coefficient

$$R_{NS} = 1 - \frac{\sum_{t=1}^{n} (Q_s^t - Q_o^t)^2}{\sum_{t=1}^{n} (Q_o^t - \overline{Q}_o)^2}$$

$\sum_{t=1}^{n} (Q_s^t - Q_o^t)^2$ → =(O32-N32)^2

$\sum_{t=1}^{n} (Q_o^t - \overline{Q}_o)^2$ → =(O32-F23)^2

where:

R_{NS}	Nash-Sutcliffe coefficient [-]
Q_s	simulated discharge $[L^3T^{-1}]$
Q_o	observed discharge $[L^3T^{-1}]$
$\bar{O}_o$	mean observed discharge $[L^3T^{-1}]$
n	number of time steps

29 30	Month ID	Temp. (C)	Preci. (mm)	Snow (mm)	Liquid Water	Soil Moisture	DQ (mm/day) OR P_{eff}	Potential E. (PE_a)	E_a (mm/day)	S_1	S_2	Total Q (Q_t) (mm/day)	Q (m^3/s) Simulations	Q (m^3/s) Observations	$(Q-QT)^2$	$(Q-Qm)^2$
31				25		100.0				2.000	200.000	1.065				
32	1	-1.5	0.4	25.4	0	99.8	0.000	0.161	0.153	1.291	199.644	0.969	4.600	4.5	0.010	0.817
33	1	-0.8	10.5	35.9	0	99.7	0.000	0.164	0.156	0.833	199.133	0.907	4.303	11	44.850	31.317
34	1	-2.8	0.9	36.8	0	99.5	0.000	0.155	0.147	0.538	198.521	0.865	4.106	6.6	6.221	1.431
35	1	-3.7	4.4	41.2	0	99.4	0.000	0.150	0.142	0.347	197.847	0.837	3.973	5	1.054	0.163
36	1	-6.1	0.6	41.8	0	99.3	0.000	0.139	0.131	0.224	197.133	0.818	3.883	4.1	0.047	1.700
37	1	-3	0	41.8	0	99.1	0.000	0.154	0.145	0.145	196.394	0.805	3.819	3.5	0.102	3.625
38	1	-0.7	4.4	46.2	0	99.0	0.000	0.165	0.155	0.093	195.640	0.795	3.772	3.2	0.327	4.857
39	1	1.8	3.1	40.8	8.5	105.9	1.413	0.177	0.167	1.473	194.879	0.974	4.624	3.2	2.028	4.857
40	1	0.6	1.7	39	3.5	108.5	0.713	0.171	0.171	1.663	194.426	0.998	4.735	5	0.070	0.163
41	1	1.8	3.6	33.6	9	115.4	1.971	0.177	0.177	3.045	194.018	1.179	5.595	7.9	5.314	6.231

Catchment Area (Km^2)	410	K_0 (Reservior Par.)	0.13
T_t (Threshold Temp.)	0	L_1 (Threshold W.L.)	6.00
DD	3	K_1 (Reservior Par.)	0.13
FC (Field Capacity)	180.0	K_2 (Reservior Par.)	0.00
BETA	3.0	K_{perc}	0.22
C (Model param.)	0.03	PWP	105.00

Monthly $T_{ave.}$	PE_m	Daily PE_m
-1.4	5	0.161
-0.3	5	0.179
2.6	20	0.645
6.3	50	1.667
10.9	95	3.065
14.2	115	3.833
16.4	125	4.032
15.6	100	3.226
12.7	70	2.333
8.3	30	0.968
2.9	10	0.333
-0.4	5	0.161

Model Performance	
TOT. ETA.	5493.37
TOT. PREC.	9887.30
TOT. DIS. (m/hr.km^2)	4393.93
SIM. DISC(m/hr.km2)	4399.65
OBS. DISC(m/hr.km2)	4157.63
Error (%)	5.821
Squar diff.	53933.17
Average $Q_{observ.}$	5.40
$(Q-Q_m)^2$	172559.78
Correlation	0.83
Nash Sutcliff	0.69

$$\sum_{t=1}^{n}(Q_s^t - Q_o^t)^2$$

$$\sum_{t=1}^{n}(Q_o^t - \overline{Q}_o)^2$$

$$R_{NS} = 1 - \frac{\sum_{t=1}^{n}(Q_s^t - Q_o^t)^2}{\sum_{t=1}^{n}(Q_o^t - \overline{Q}_o)^2}$$

Date	Month ID	Temp. (C)	Preci. (mm)	Snow (mm)	Liquid Water
				25	
1/1/1991	1	-1.5	0.4	25.4	0
1/2/1991	1	-0.8	10.5	35.9	0
1/3/1991	1	-2.8	0.9	36.8	0
1/4/1991	1	-3.7	4.4	41.2	0
1/5/1991	1	-6.1	0.6	41.8	0
1/6/1991	1	-3	0	41.8	0
1/7/1991	1	-0.7	4.4	46.2	0
1/8/1991	1	1.8	3.1	40.8	8.5
1/9/1991	1	0.6	1.7	39	3.5
1/10/1991	1	1.8	3.6	33.6	9

HBV CONCEPT | Snow Accum | S1 | S2 | Output

Model Parameters

Conceptual	Conceptual & Measurable	Initial Conditions
• BETA (β) • C • L • K_0 • K_1 • K_2 • K_{perc}	• FC • DD • PWP • T_t	• Snow • Soil Moisture • S_1 • S_2

Error Sources

Error in Initial Conditions

- Error in the initial values of soil moisture, snow, field capacity, permanent wilting point

Error in Model Processes

- Unrealistic model assumptions
- Unrepresentative conceptual description of the system

Error in Observations

- Error in input data (e.g., precipitation, temperature, etc.)
- Error in observed discharge

Error in Model Parameterization

- Inability to obtain the optimal set of parameters.
- Deficiencies in parameter estimation scheme

Error Sources

Error in Initial Conditions

- Error in the initial values of soil moisture, snow, field capacity, permanent wilting point

Error in Model Processes

- Unrealistic model assumptions
- Unrepresentative … f th…

Error in Observations

- Error in input data (e.g., precipitation, …e, etc.)
- …served

Error in Model Parameterization

- Inability to obtain the optimal set of parameters.
- Deficiencies in parameter estimation scheme

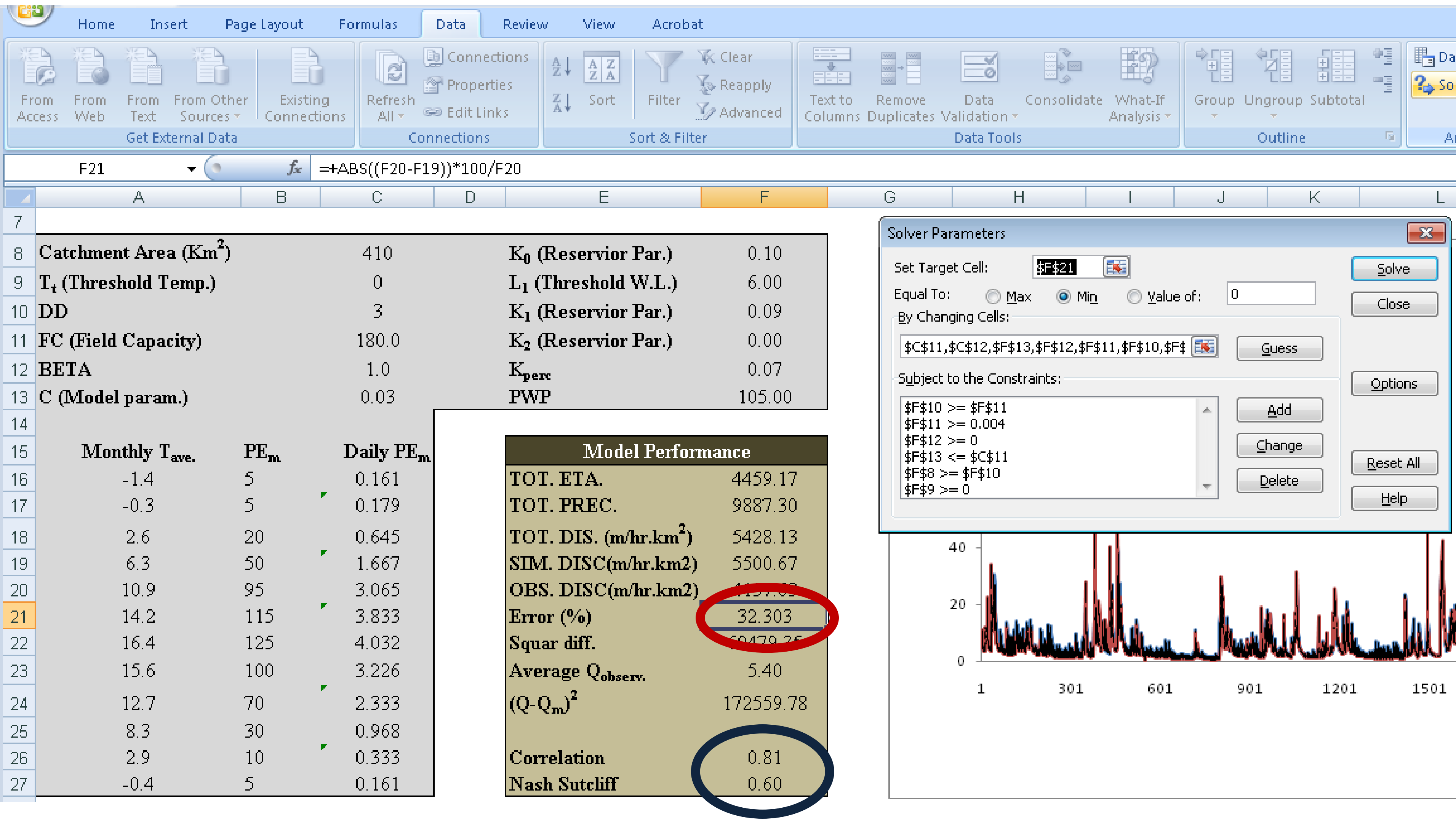
Conceptual

- BETA (β)
- C
- L
- K_0
- K_1
- K_2
- K_{perc}

Conceptual & Measurable

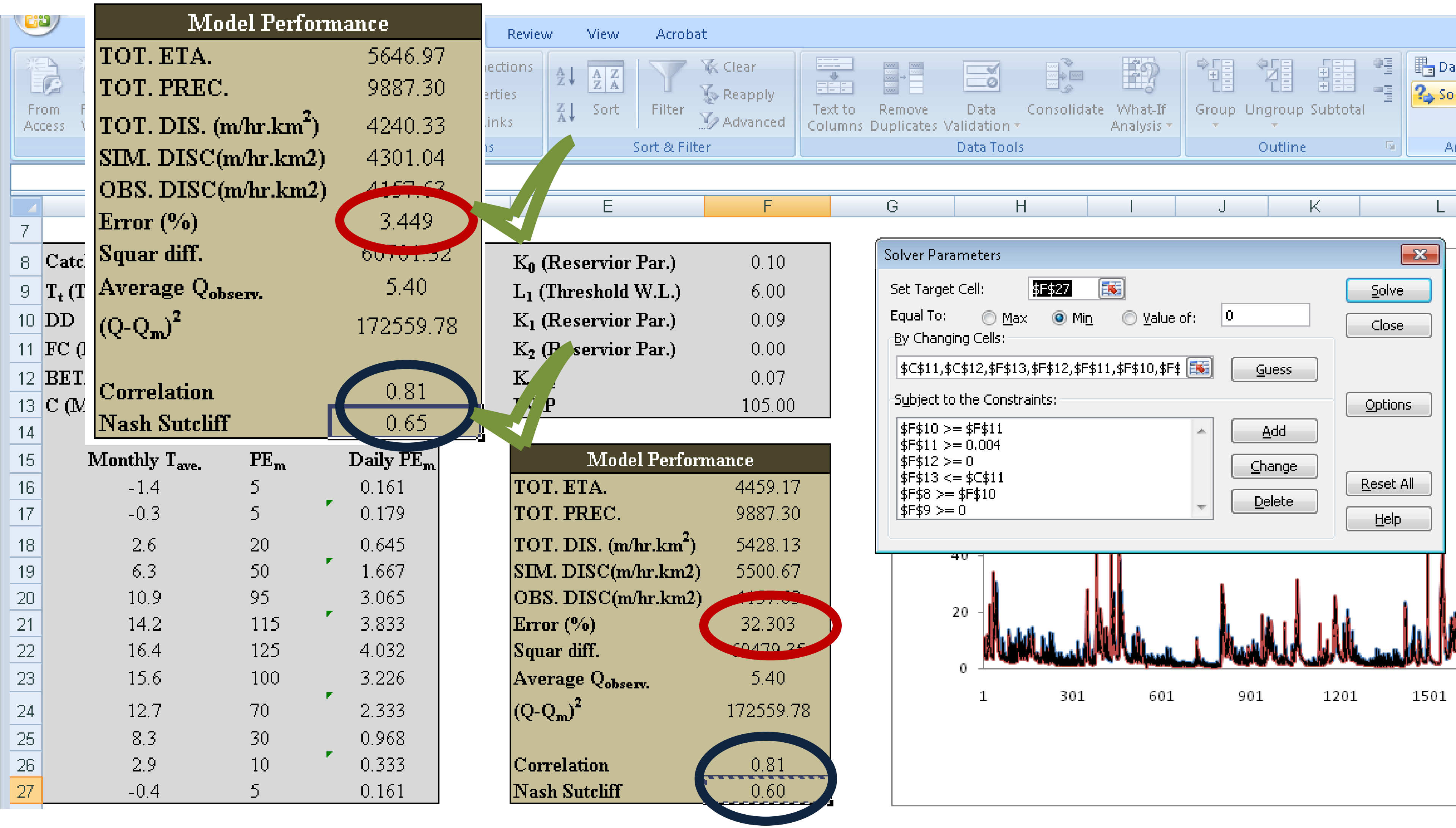
- FC
- DD
- PWP
- T_t

Parameter Estimation

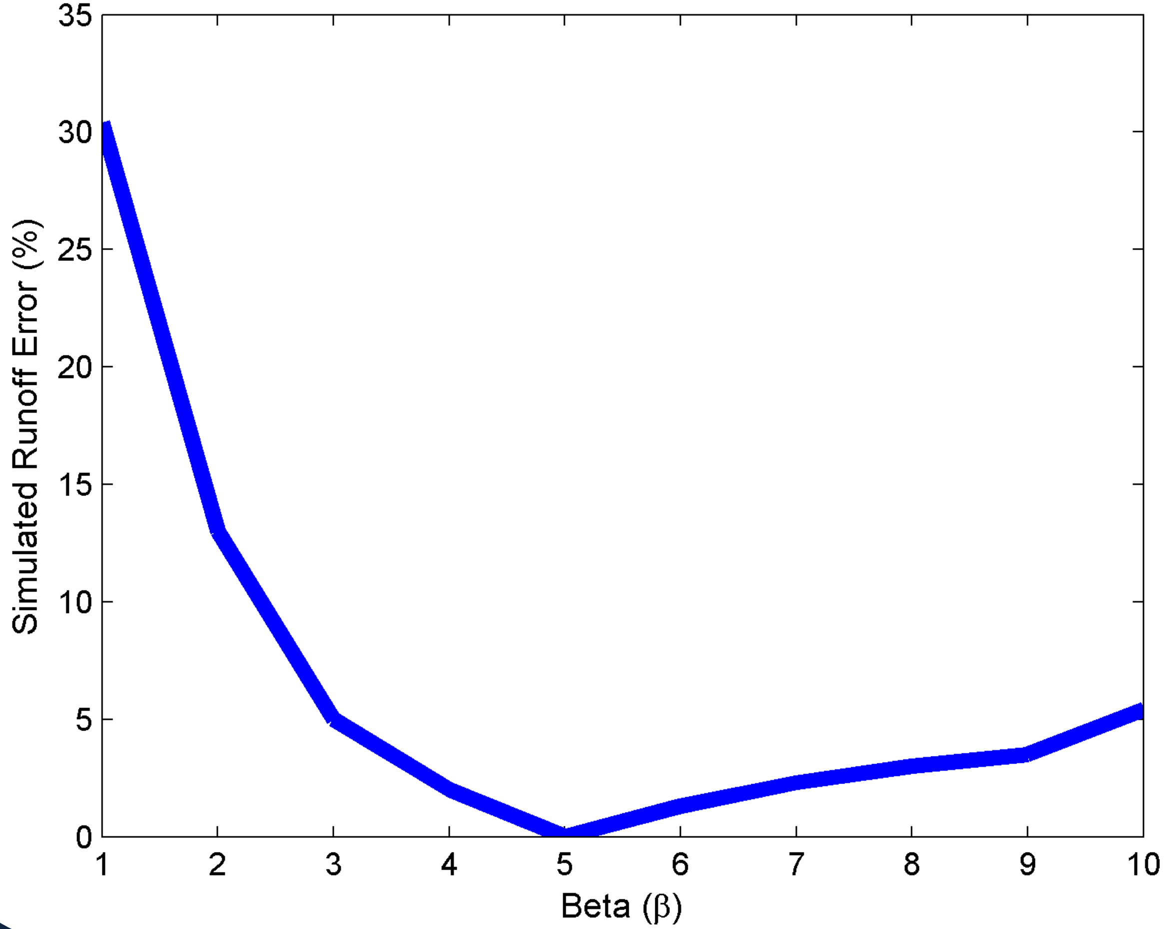


Parameter Estimation

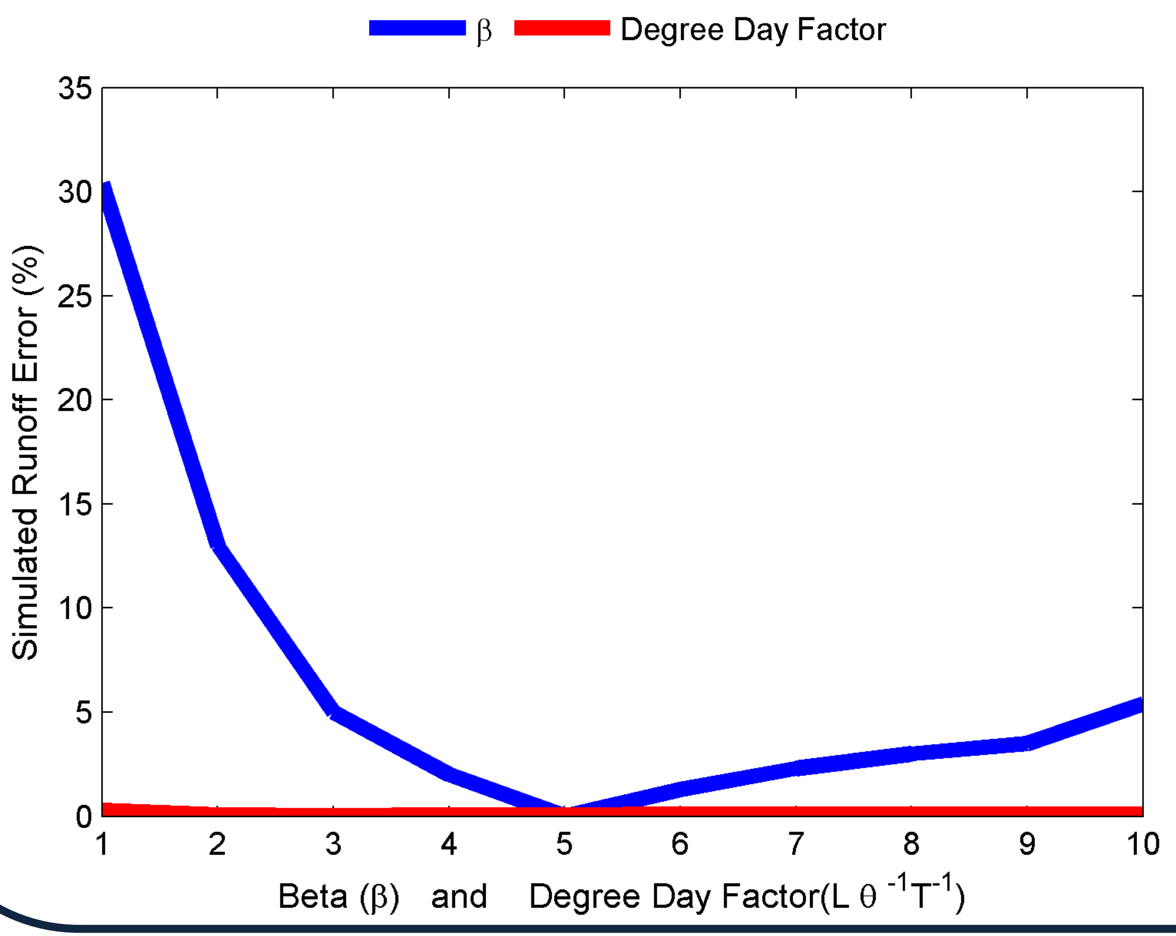
After Calibration



Parameter Sensitivity



Parameter Sensitivity



Error Sources

Error in Initial Conditions

- Error in the initial values of soil moisture, snow, field capacity, permanent wilting point

Error in Model Processes

- Unrealistic model assumptions
- Unrepresentative conceptual description of the system

Error in Observations

- Error in input data (e.g., precipitation, temperature, etc.)
- Error in observed discharge

Error in Model Parameterization

- Inability to obtain the optimal set of parameters.
- Deficiencies in parameter estimation scheme

Initial Conditions

- Snow
- Soil Moisture
- S_1
- S_2

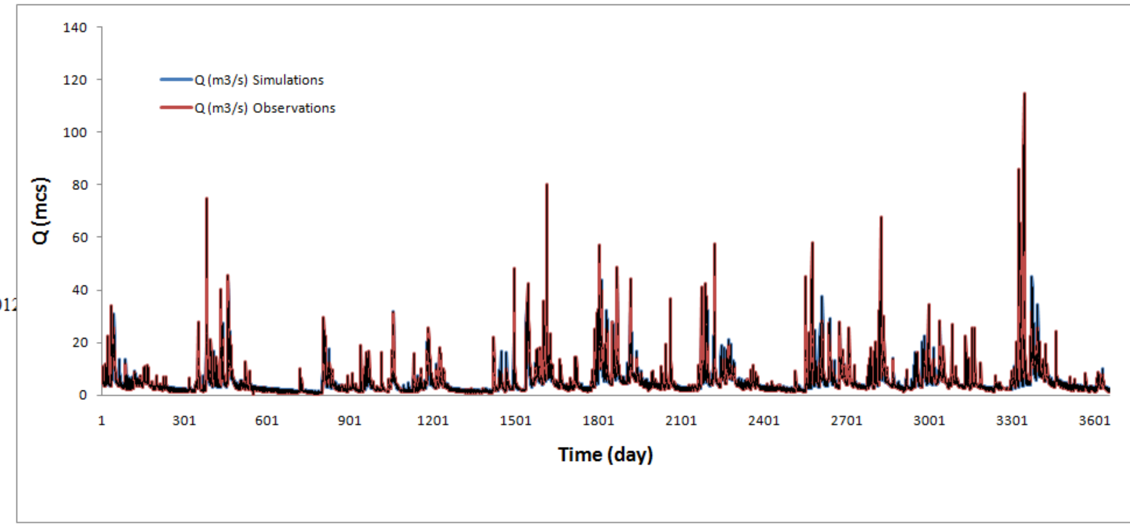
Initial Condition Error

Catchment Area (Km^2)	410	K_0 (Reservior Par.)	0.13
T_t (Threshold Temp.)	0	L_1 (Threshold W.L.)	6.00
DD	3	K_1 (Reservior Par.)	0.13
FC (Field Capacity)	180.0	K_2 (Reservior Par.)	0.00
BETA	5.0	K_{perc}	0.22
C (Model param.)	0.03	PWP	105.00

Monthly $T_{ave.}$	PE_m	Daily PE_m
-1.4	5	0.161
-0.3	5	0.179
2.6	20	0.645
6.3	50	1.667
10.9	95	3.065
14.2	115	3.833
16.4	125	4.032
15.6	100	3.226
12.7	70	2.333
8.3	30	0.968
2.9	10	0.333
-0.4	5	0.161

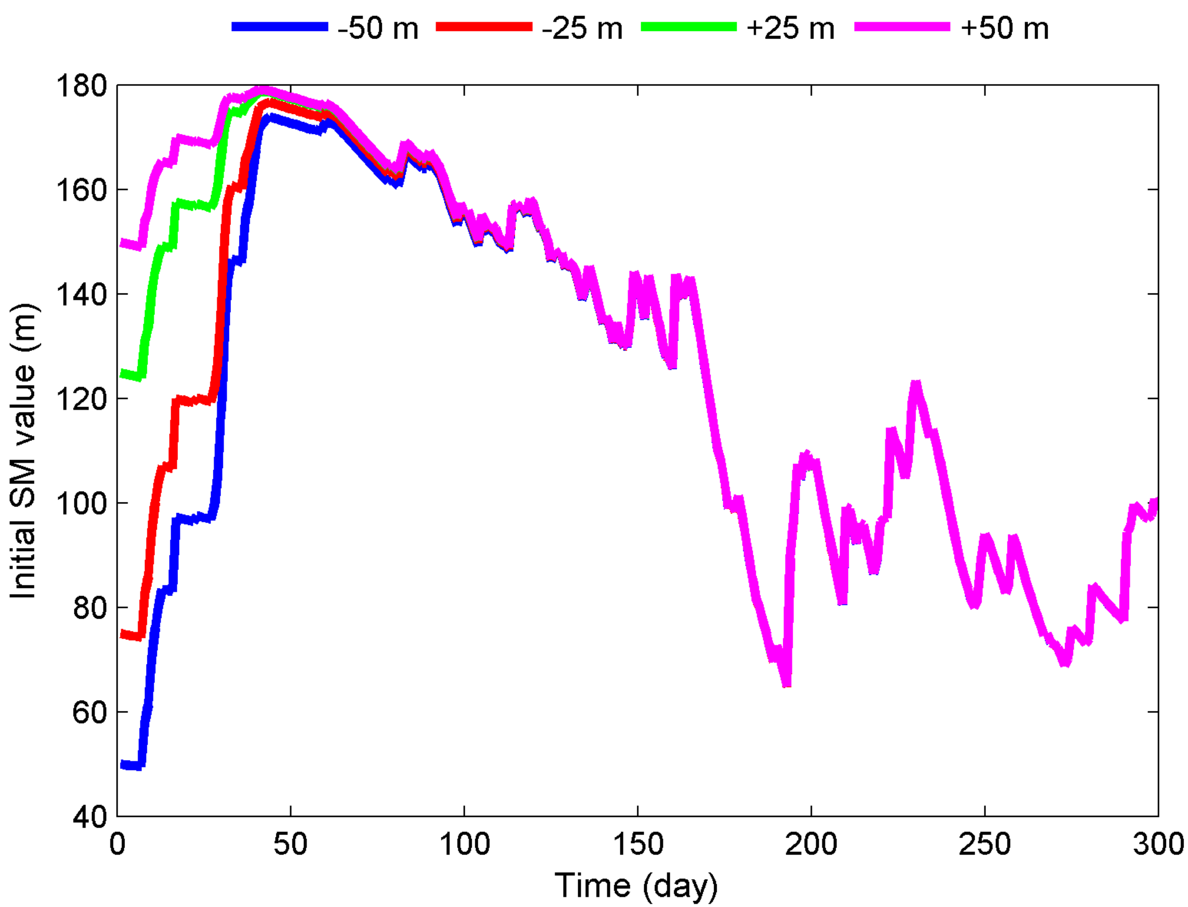
Model Performance	
TOT. ETA.	5736.08
TOT. PREC.	9887.30
TOT. DIS. (m/hr.km^2)	4151.22
SIM. DISC(m/hr.km2)	4157.68
OBS. DISC(m/hr.km2)	4157.63
Error (%)	0.001
Squar diff.	52400.87
Average $Q_{observ.}$	5.40
$(Q-Q_m)^2$	172559.78
Correlation	0.84
Nash Sutcliff	0.70

1.000012



Date	Month ID	Temp. (C)	Preci. (mm)	Snow (mm)	Liquid Water	Soil Moisture	DQ (mm/day) OR P_{eff}	Potential E. (PE_a)	E_a (mm/day)	S_1	S_2	Total Q (Q_t) (mm/day)	Q (m^3/s) Simulations	Q (m^3/s) Observations	$(Q-QT)^2$	$(Q-Qm)^2$
				25		100.0				2.000	200.000	1.065				
1/1/1991	1	-1.5	0.4	25.4	0	99.8	0.000	0.161	0.153	1.291	199.644	0.969	4.600	4.5	0.010	0.817
1/2/1991	1	-0.8	10.5	35.9	0	99.7	0.000	0.164	0.156	0.833	199.133	0.907	4.303	11	44.850	31.317
1/3/1991	1	-2.8	0.9	36.8	0	99.5	0.000	0.155	0.147	0.538	198.521	0.865	4.106	6.6	6.221	1.431
1/4/1991	1	-3.7	4.4	41.2	0	99.4	0.000	0.150	0.142	0.347	197.847	0.837	3.973	5	1.054	0.163
1/5/1991	1	-6.1	0.6	41.8	0	99.3	0.000	0.139	0.131	0.224	197.133	0.818	3.883	4.1	0.047	1.700

Initial Condition Error



Initial Condition Error

Butterfly Effect

Sensitive dependence on initial conditions

small variations in the initial condition of a dynamic model may lead to large differences in the behavior of the system.

Initial Condition Error

Butterfly Effect

Edward N. Lorenz
1917-2008

Meteorologist
Massachusetts Institute of Technology

Error Sources

Error in Initial Conditions

- Error in the initial values of soil moisture, snow, field capacity, permanent wilting point

Error in Model Processes

- Unrealistic model assumptions
- Unrepresentative conceptual description of the system

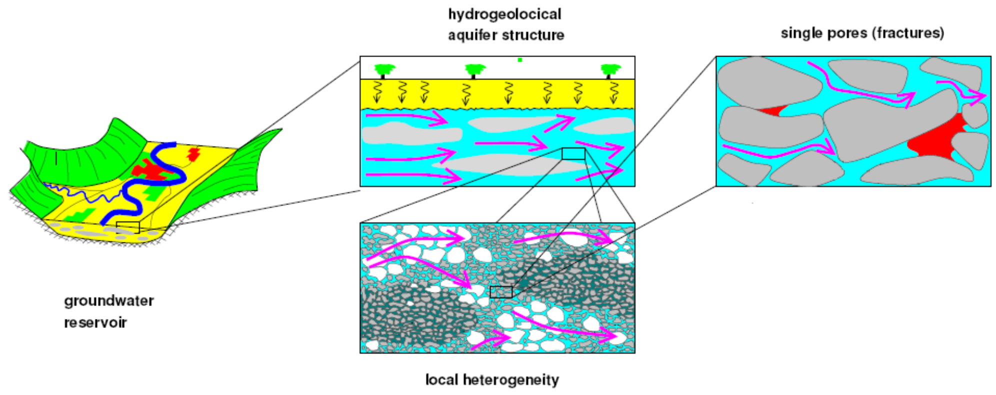
Error in Observations

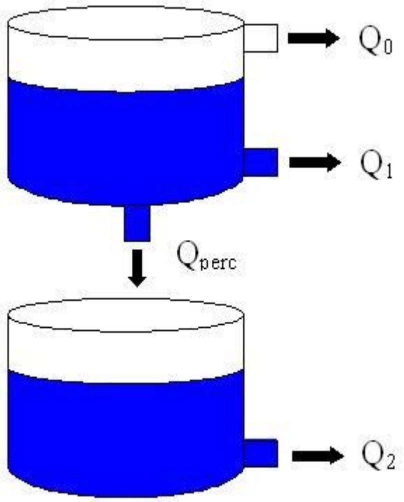
- Error in input data (e.g., precipitation, temperature, etc.)
- Error in observed discharge

Error in Model Parameterization

- Inability to obtain the optimal set of parameters.
- Deficiencies in parameter estimation scheme

Error in Model Processes





Error Sources

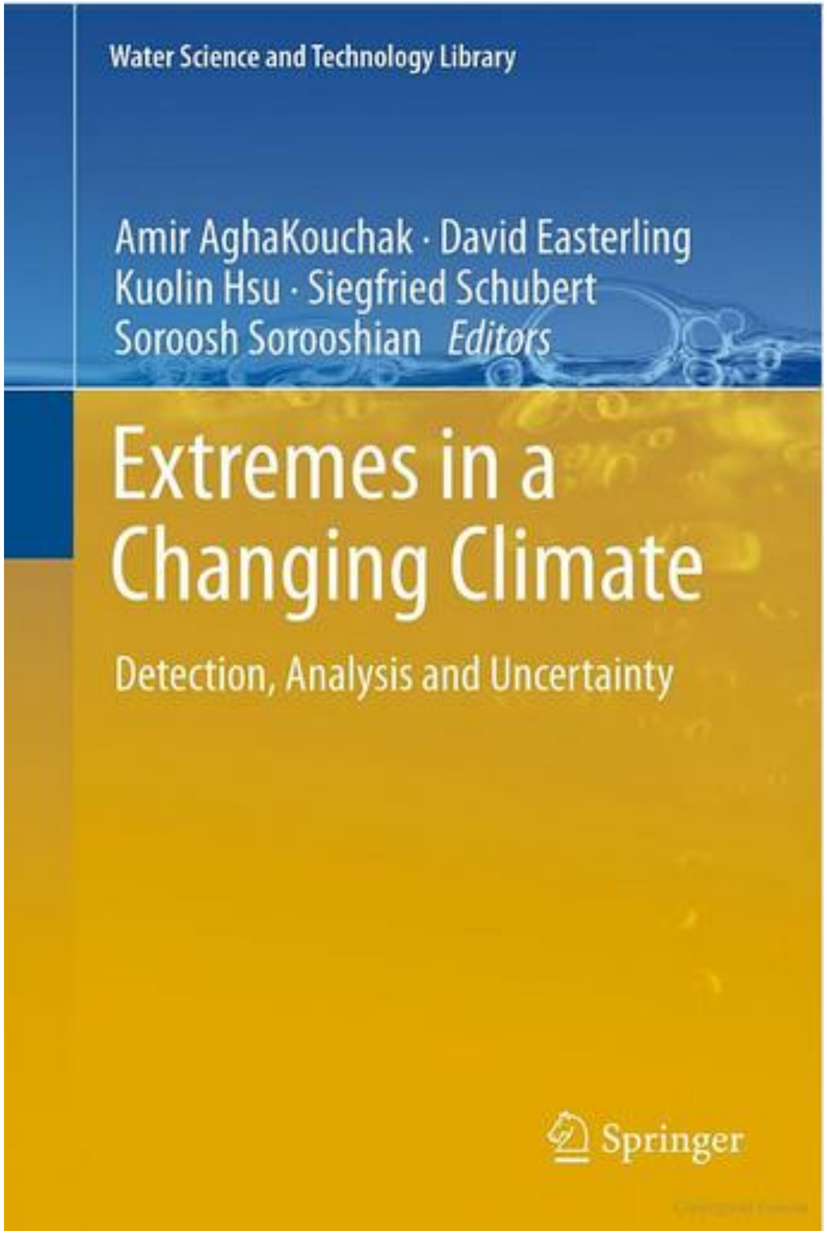
Error in Initial Conditions	Error in Model Processes	Error in Observations	Error in Model Parameterization
• Error in the initial values of soil moisture, snow, field capacity, permanent wilting point	• Unrealistic model assumptions • Unrepresentative conceptual description of the system	• Error in input data (e.g., precipitation, temperature, etc.) • Error in observed discharge	• Inability to obtain the optimal set of parameters. • Deficiencies in parameter estimation scheme

Error in Observations

Temp. (C)	Preci. (mm)	Q (m^3/s) Simulati	Q (m^3/s) Observat
-1.5	0.4	4.6	4.5
-0.8	10.5	4.3	11.0
-2.8	0.9	4.1	6.6
-3.7	4.4	4.0	5.0
-6.1	0.6	3.9	4.1
-3.0	0.0	3.8	3.5
-0.7	4.4	3.8	3.2
1.8	3.1	4.0	3.2
0.6	1.7	4.0	5.0
1.8	3.6	4.4	7.9
1.2	2.4	4.6	11.9
1.5	0.0	4.7	10.4
1.1	0.0	4.7	10.4
-0.5	0.0	4.3	8.5
-3.2	1.3	4.1	6.8
-0.9	0.6	3.9	6.1
3.2	5.0	5.5	11.6
-1.5	20.7	4.8	22.5
-2.8	8.4	4.4	12.3
-5.1	1.5	4.1	9.2
-2.9	2.4	3.9	7.3
-0.6	0.9	3.8	6.1
0.1	0.9	3.9	5.2
-0.8	1.2	3.8	4.5

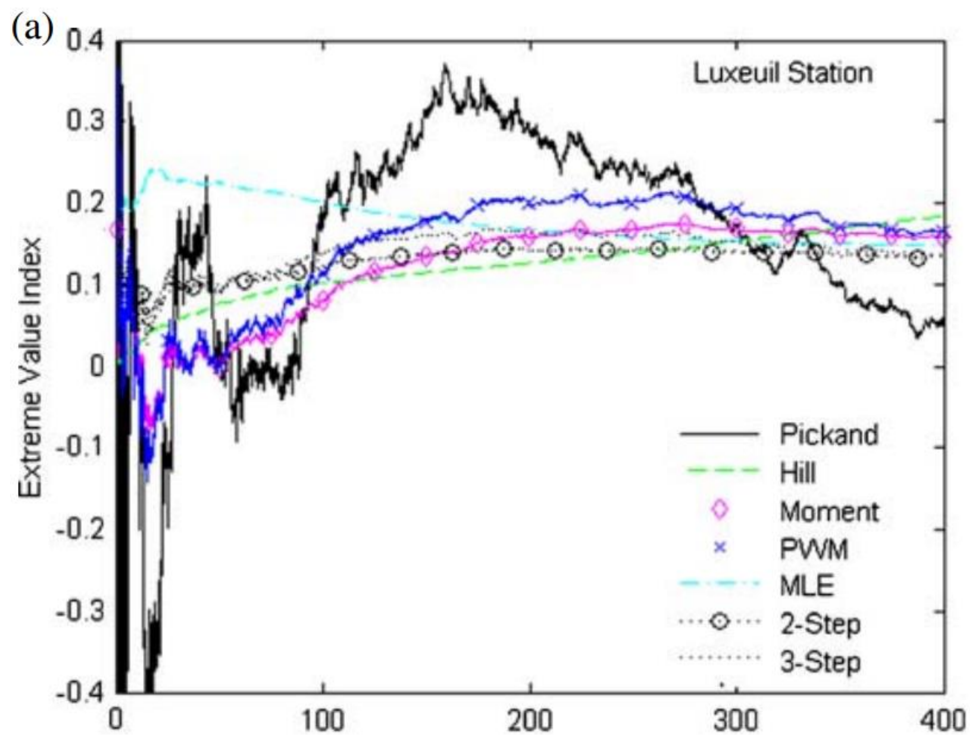
Model Performance	
TOT. ETA.	5736.08
TOT. PREC.	9887.30
TOT. DIS. ($m/hr.km^2$)	4151.22
SIM. DISC(m/hr.km2)	4157.68
OBS. DISC(m/hr.km2)	4157.63
Error (%)	0.001
Squar diff.	52400.87
Average $Q_{observ.}$	5.40
$(Q-Q_m)^2$	172559.78
Correlation	0.84
Nash Sutcliff	0.70

Example Applications of the Model

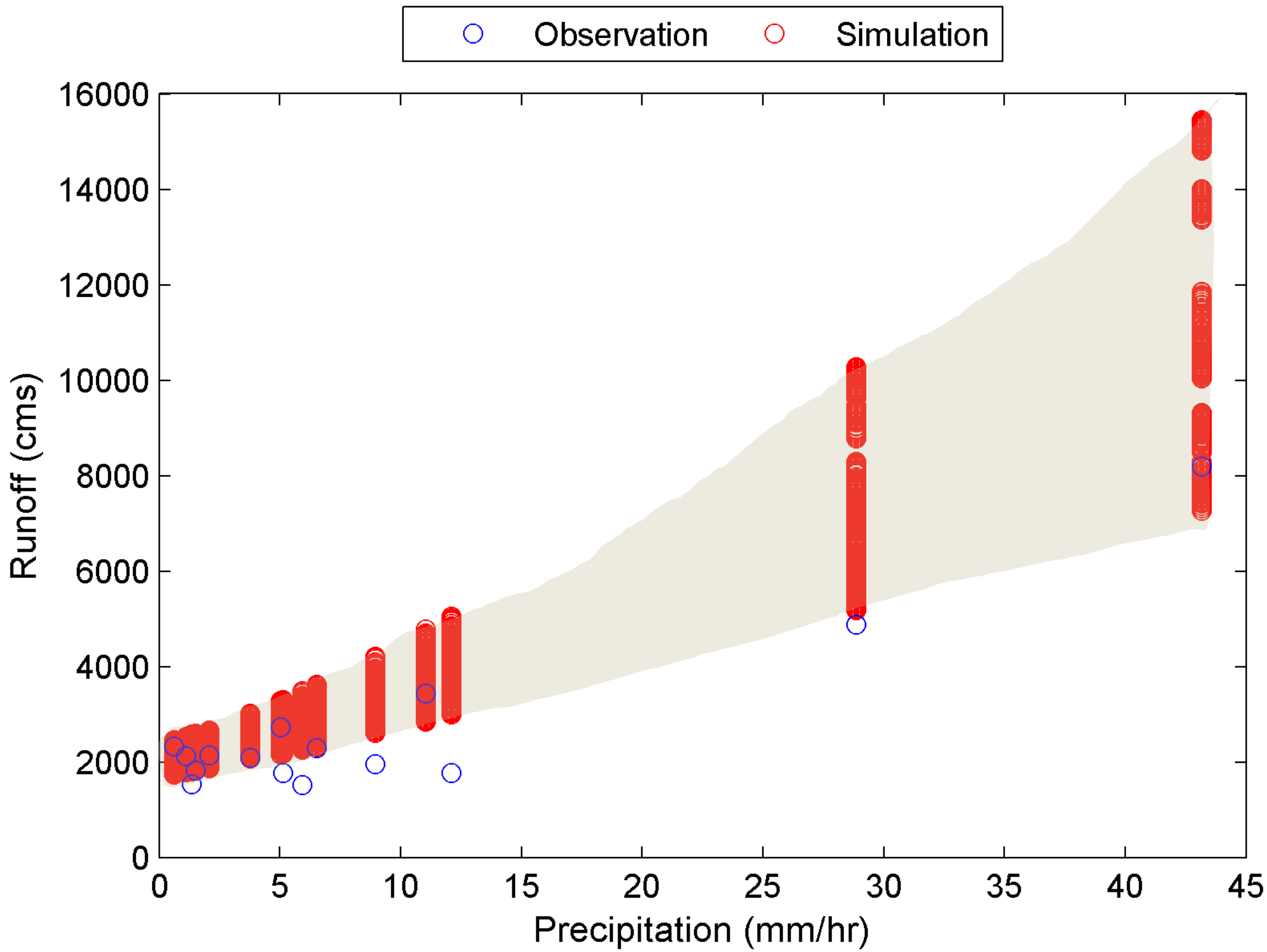


1- Run the model with different GCM outputs

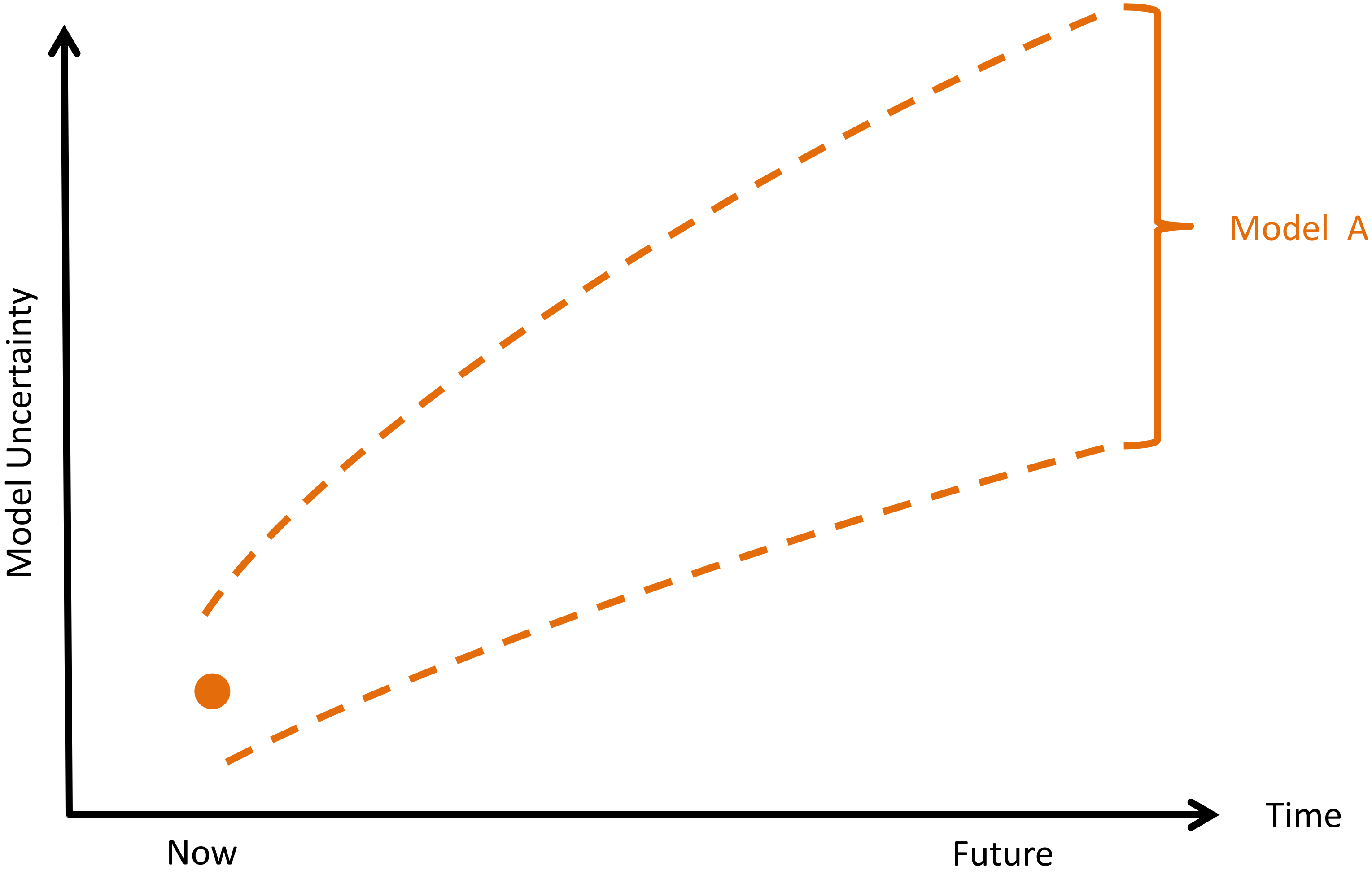
2- Analyze data using the Extreme Value Theory



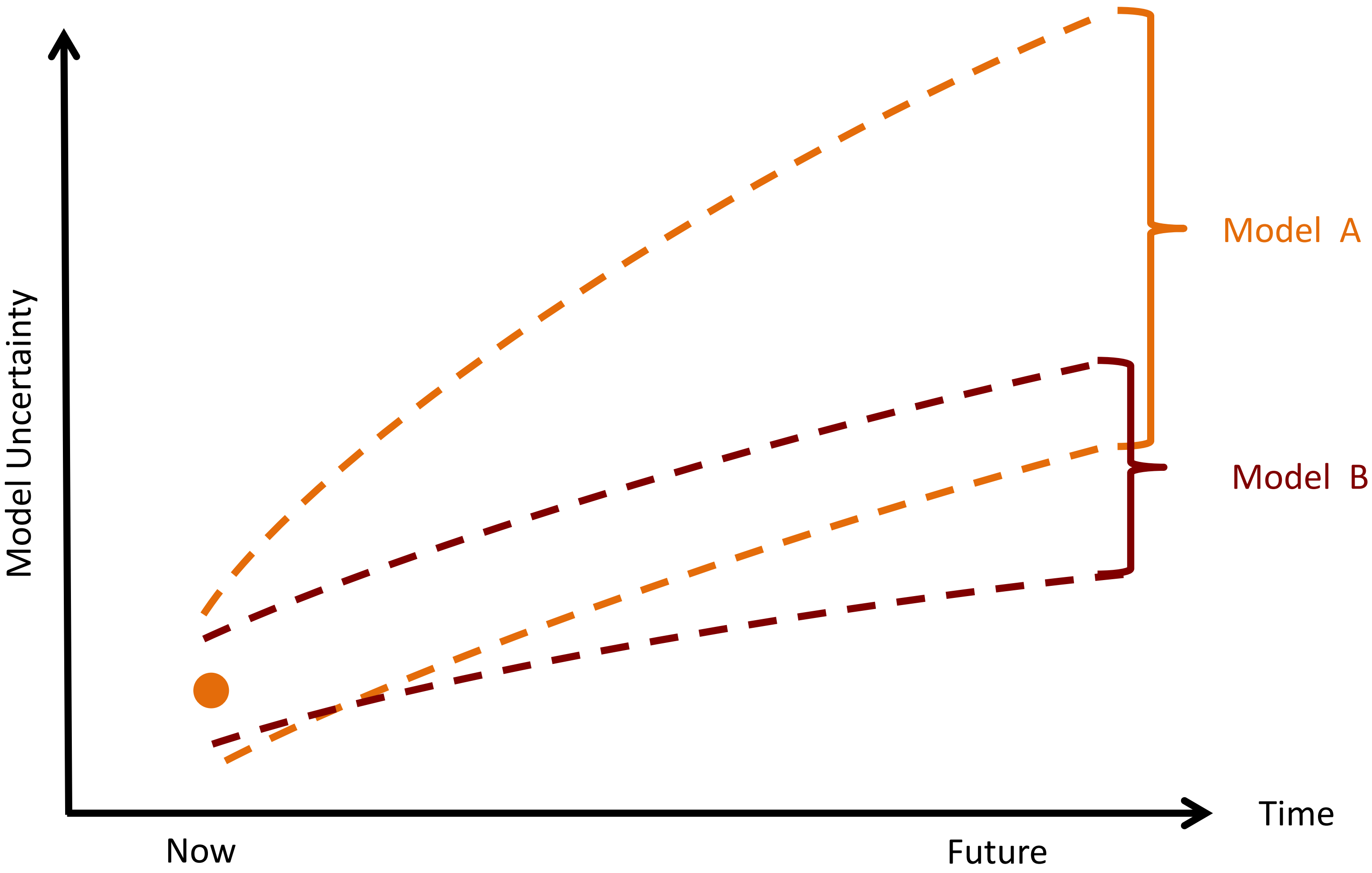
Model Uncertainty – Ensemble Simulation



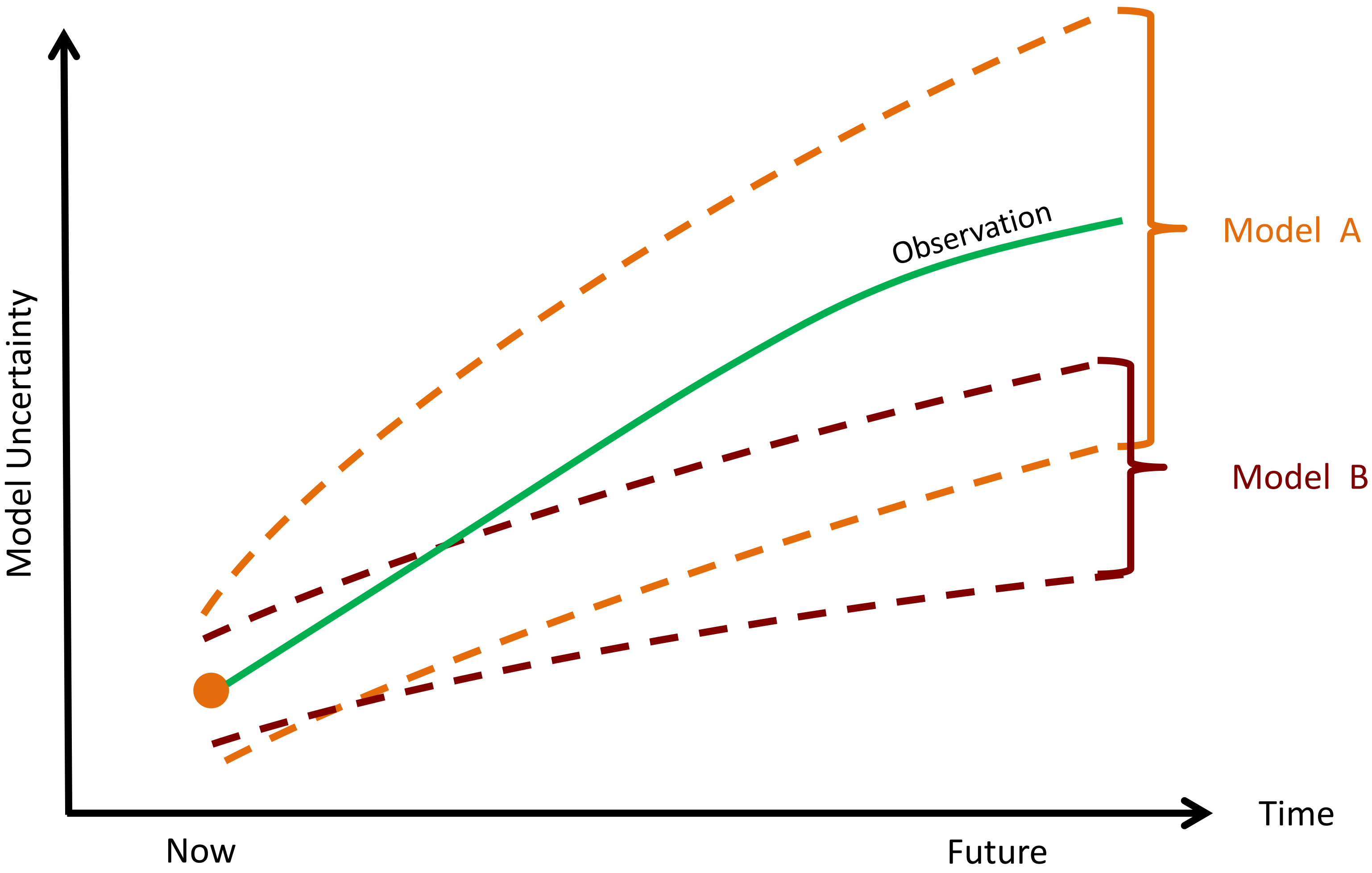
Model Uncertainty



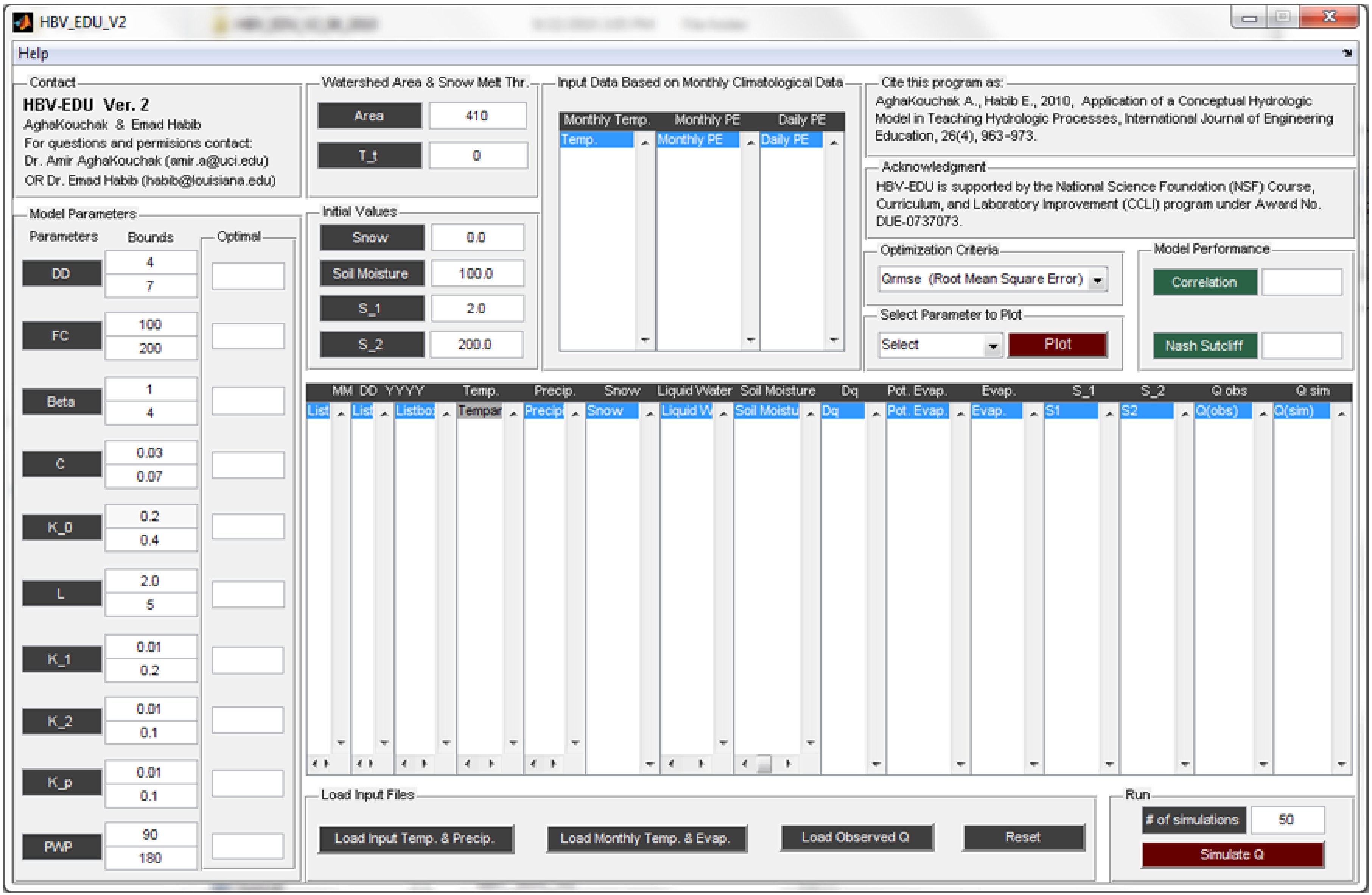
Model Uncertainty



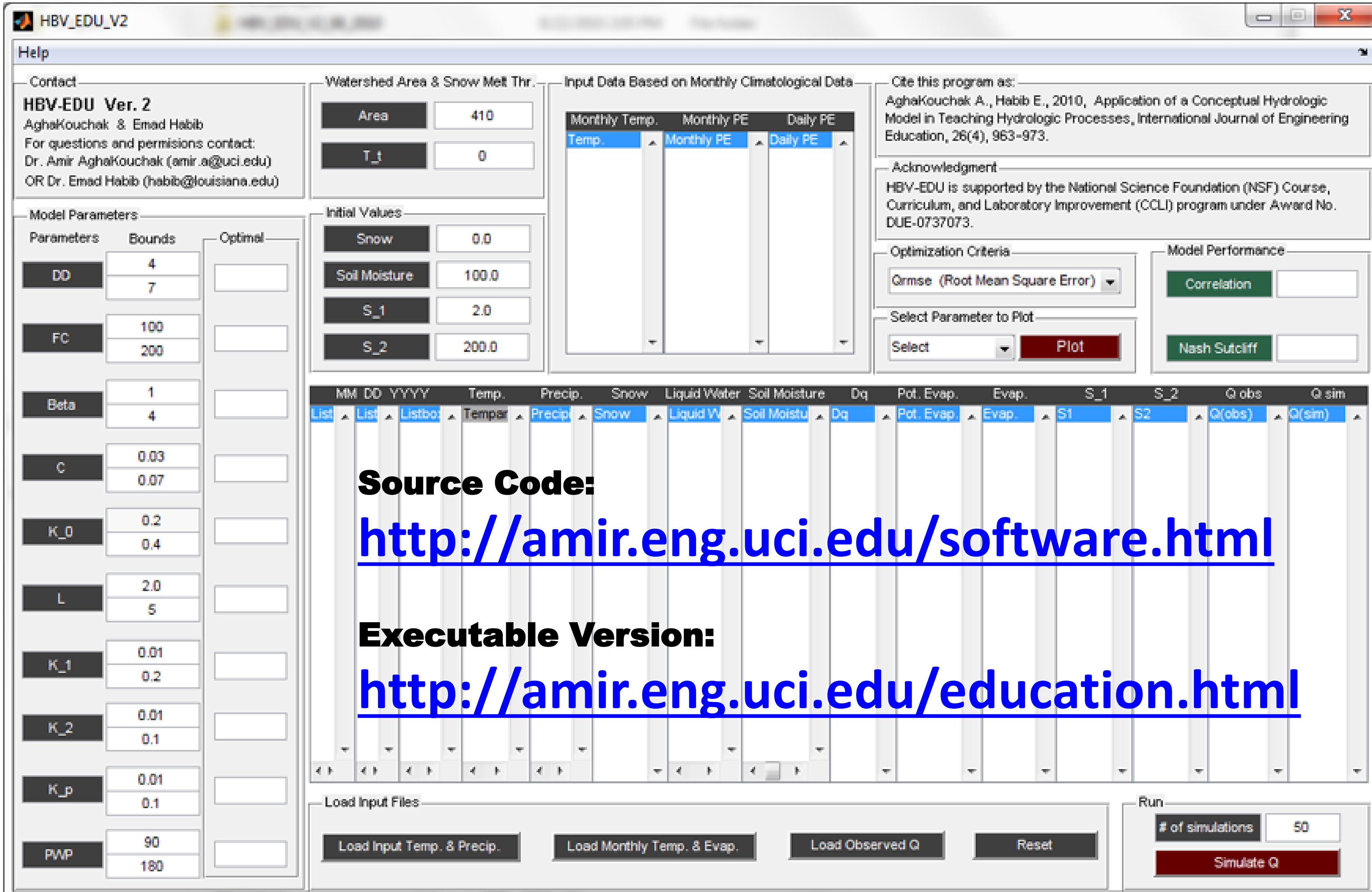
Model Uncertainty



HBV-EDU


HBV_EDU_V2
Help
Contact
HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permisions contact:
Dr. Amir AghaKouchak (amir.a@uci.edu)
OR Dr. Emad Habib (habib@louisiana.edu)
Watershed Area & Snow Melt Thr.
Area
410
T_t
0
Input Data Based on Monthly Climatological Data
Monthly Temp.
Monthly PE
Daily PE
Cite this program as:
AghaKouchak A., Habib E., 2010, Application of a Conceptual Hydrologic Model in Teaching Hydrologic Processes, International Journal of Engineering Education, 26(4), 963-973.
Acknowledgment
HBV-EDU is supported by the National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement (CCLI) program under Award No. DUE-0737073.
Model Parameters
Parameters
Bounds
Optimal
DD 4 7
FC 100 200
Beta 1 4
C 0.03 0.07
K_0 0.2 0.4
L 2.0 5
K_1 0.01 0.2
K_2 0.01 0.1
K_p 0.01 0.1
PWP 90 180
Initial Values
Snow 0.0
Soil Moisture 100.0
S_1 2.0
S_2 200.0
Optimization Criteria
Qrmse (Root Mean Square Error)
Select Parameter to Plot
Select
Plot
Model Performance
Correlation
Nash Sutcliff
MM DD YYYY Temp. Precip. Snow Liquid Water Soil Moisture Dq Pot. Evap. Evap. S_1 S_2 Q obs Q sim
Load Input Files
Load Input Temp. & Precip.
Load Monthly Temp. & Evap.
Load Observed Q
Reset
Run
# of simulations
50
Simulate Q

HBV-EDU



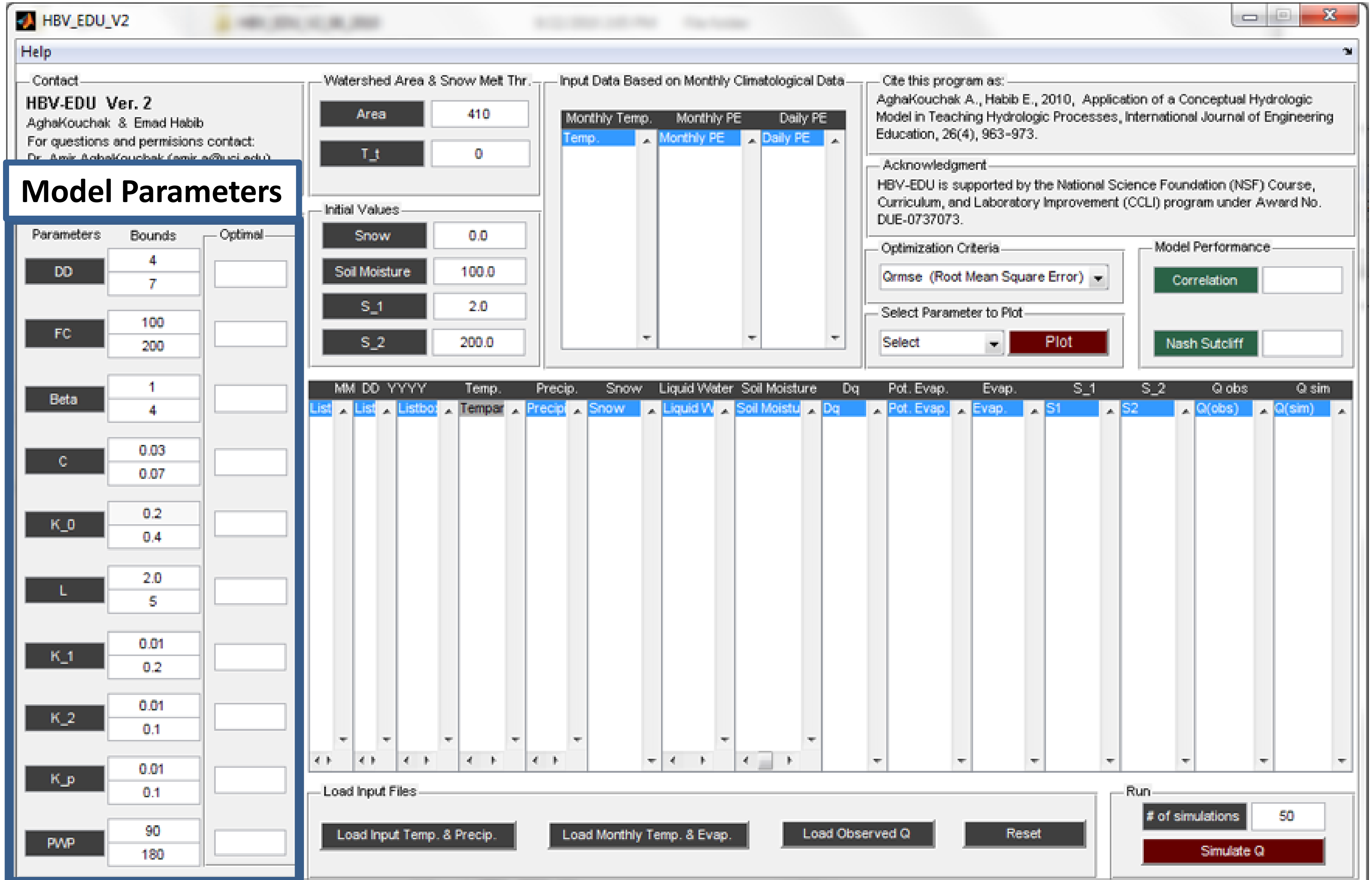
Source Code:

http://amir.eng.uci.edu/software.html

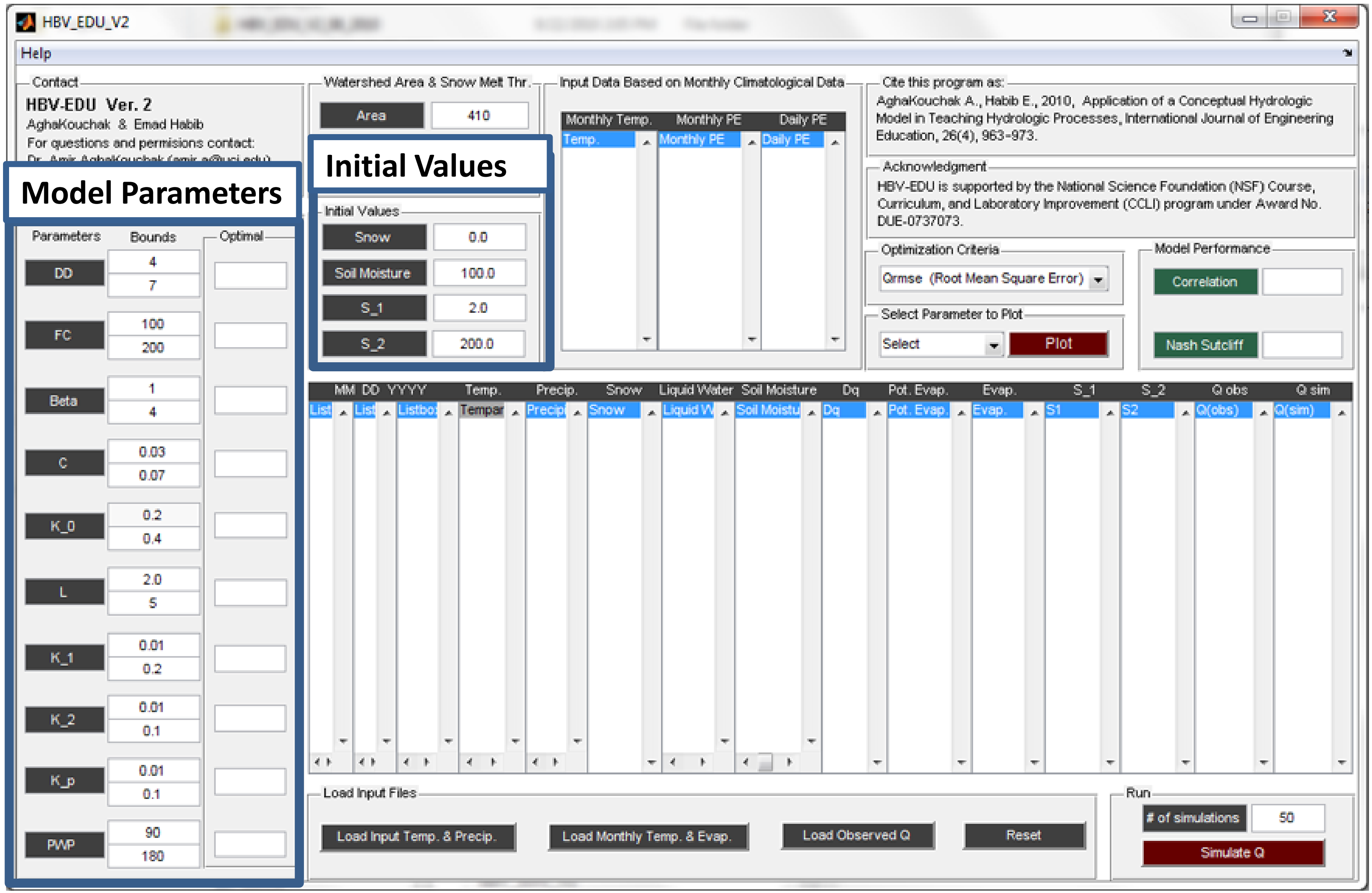
Executable Version:

http://amir.eng.uci.edu/education.html

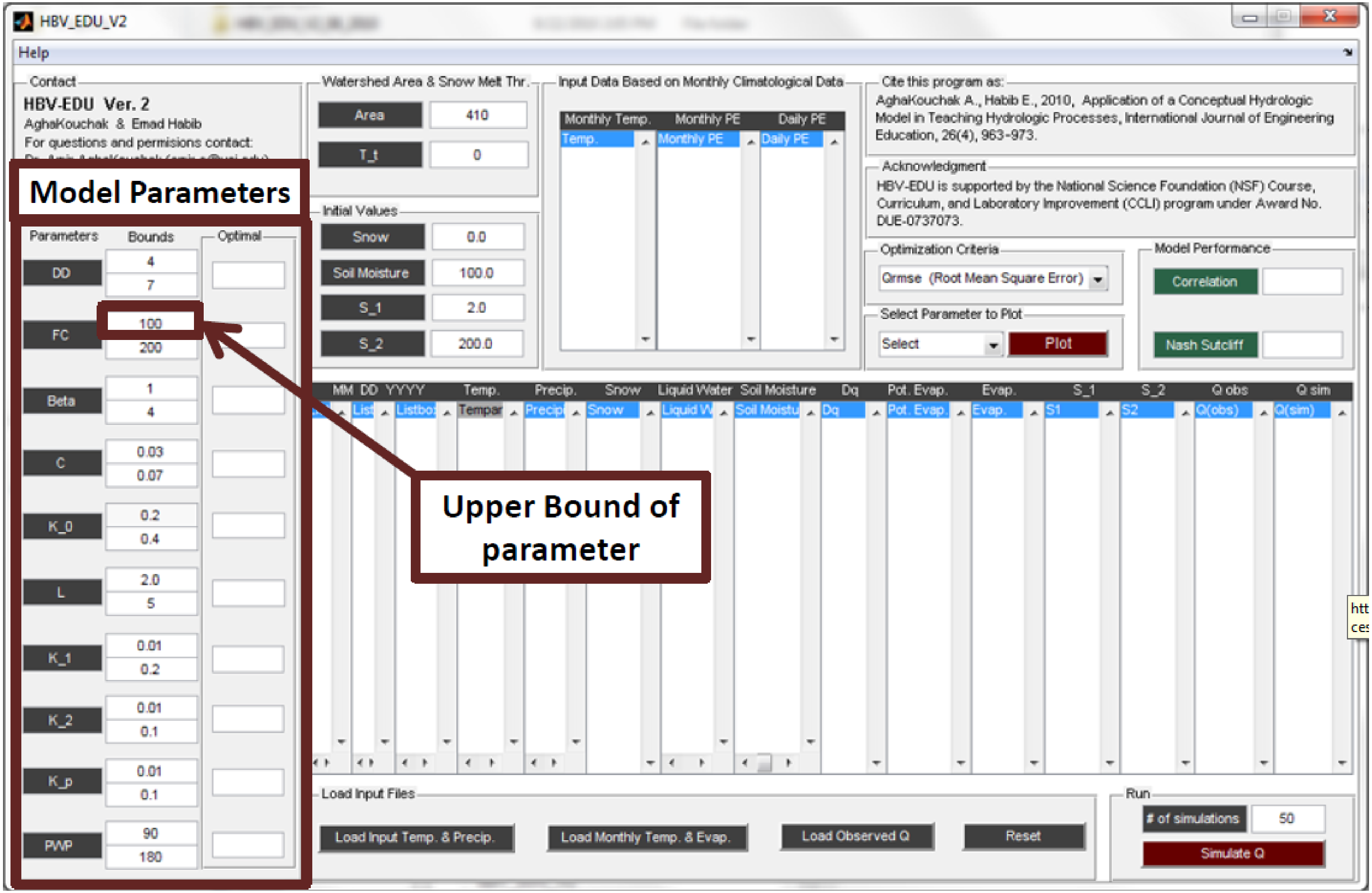
HBV-EDU


HBV_EDU_V2
Help
Contact
HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permisions contact:
Model Parameters
Parameters
Bounds
Optimal
DD
4
7
FC
100
200
Beta
1
4
C
0.03
0.07
K_0
0.2
0.4
L
2.0
5
K_1
0.01
0.2
K_2
0.01
0.1
K_p
0.01
0.1
PWP
90
180
Watershed Area & Snow Melt Thr.
Area
410
T_t
0
Initial Values
Snow
0.0
Soil Moisture
100.0
S_1
2.0
S_2
200.0
Input Data Based on Monthly Climatological Data
Monthly Temp.
Monthly PE
Daily PE
Cite this program as:
AghaKouchak A., Habib E., 2010, Application of a Conceptual Hydrologic Model in Teaching Hydrologic Processes, International Journal of Engineering Education, 26(4), 963-973.
Acknowledgment
HBV-EDU is supported by the National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement (CCLI) program under Award No. DUE-0737073.
Optimization Criteria
Qrmse (Root Mean Square Error)
Select Parameter to Plot
Select
Plot
Model Performance
Correlation
Nash Sutcliff
MM DD YYYY
Temp.
Precip.
Snow
Liquid Water
Soil Moisture
Dq
Pot. Evap.
Evap.
S_1
S_2
Q obs
Q sim
Load Input Files
Load Input Temp. & Precip.
Load Monthly Temp. & Evap.
Load Observed Q
Reset
Run
# of simulations
50
Simulate Q

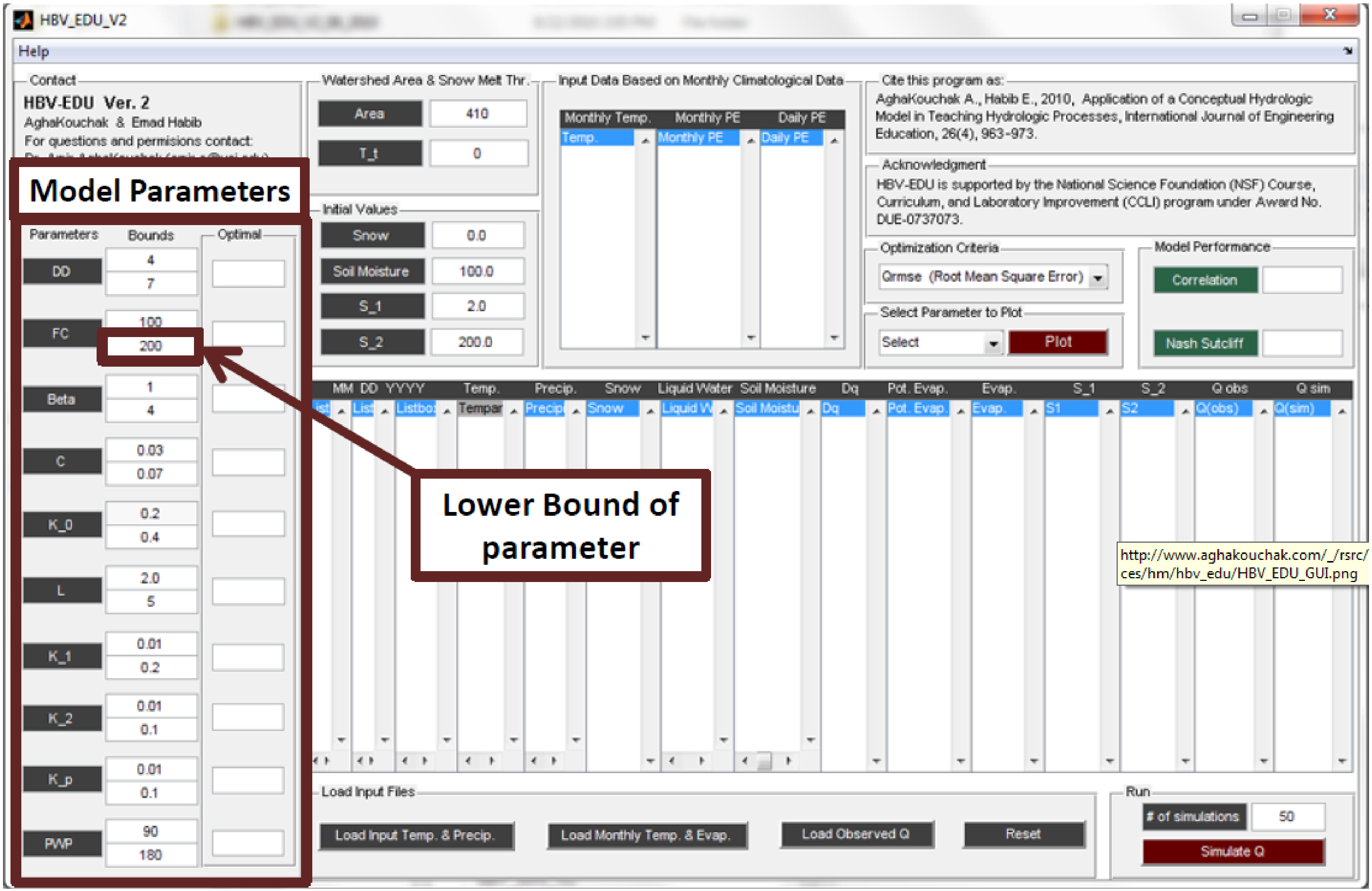
HBV-EDU


HBV_EDU_V2
Help
Contact
HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permisions contact:
Model Parameters
Parameters
Bounds
Optimal
DD
4
7
FC
100
200
Beta
1
4
C
0.03
0.07
K_0
0.2
0.4
L
2.0
5
K_1
0.01
0.2
K_2
0.01
0.1
K_p
0.01
0.1
PWP
90
180
Watershed Area & Snow Melt Thr.
Area
410
Initial Values
Initial Values
Snow
0.0
Soil Moisture
100.0
S_1
2.0
S_2
200.0
Input Data Based on Monthly Climatological Data
Monthly Temp.
Monthly PE
Daily PE
Temp.
Monthly PE
Daily PE
Cite this program as:
AghaKouchak A., Habib E., 2010, Application of a Conceptual Hydrologic Model in Teaching Hydrologic Processes, International Journal of Engineering Education, 26(4), 963-973.
Acknowledgment
HBV-EDU is supported by the National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement (CCLI) program under Award No. DUE-0737073.
Optimization Criteria
Qrmse (Root Mean Square Error)
Select Parameter to Plot
Select
Plot
Model Performance
Correlation
Nash Sutcliff
MM DD YYYY
Temp.
Precip.
Snow
Liquid Water
Soil Moisture
Dq
Pot. Evap.
Evap.
S_1
S_2
Q obs
Q sim
Load Input Files
Load Input Temp. & Precip.
Load Monthly Temp. & Evap.
Load Observed Q
Reset
Run
# of simulations
50
Simulate Q

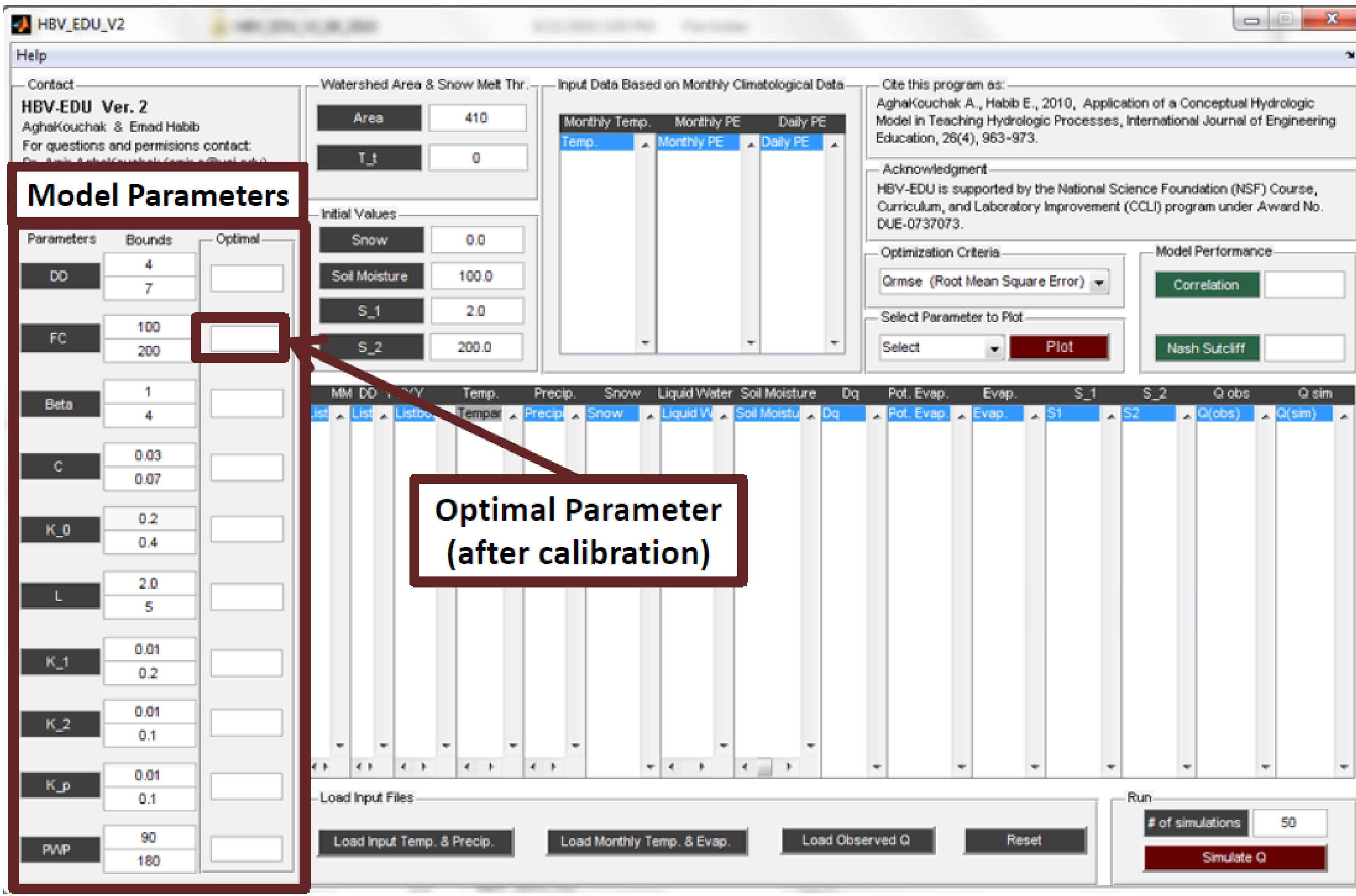
HBV-EDU


HBV_EDU_V2
Help
Contact
HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permisions contact:
Model Parameters
Parameters
Bounds
Optimal
DD
4
7
FC
100
200
Beta
1
4
C
0.03
0.07
K_0
0.2
0.4
L
2.0
5
K_1
0.01
0.2
K_2
0.01
0.1
K_p
0.01
0.1
PWP
90
180
Watershed Area & Snow Melt Thr.
Area
410
T_t
0
Initial Values
Snow
0.0
Soil Moisture
100.0
S_1
2.0
S_2
200.0
Input Data Based on Monthly Climatological Data
Monthly Temp.
Monthly PE
Daily PE
Cite this program as:
AghaKouchak A., Habib E., 2010, Application of a Conceptual Hydrologic Model in Teaching Hydrologic Processes, International Journal of Engineering Education, 26(4), 963-973.
Acknowledgment
HBV-EDU is supported by the National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement (CCLI) program under Award No. DUE-0737073.
Optimization Criteria
Qrmse (Root Mean Square Error)
Model Performance
Correlation
Nash Sutcliff
Select Parameter to Plot
Select
Plot
MM DD YYYY
Temp.
Precip.
Snow
Liquid Water
Soil Moisture
Dq
Pot. Evap.
Evap.
S_1
S_2
Q obs
Q sim
Upper Bound of parameter
Load Input Files
Load Input Temp. & Precip.
Load Monthly Temp. & Evap.
Load Observed Q
Reset
Run
# of simulations
50
Simulate Q

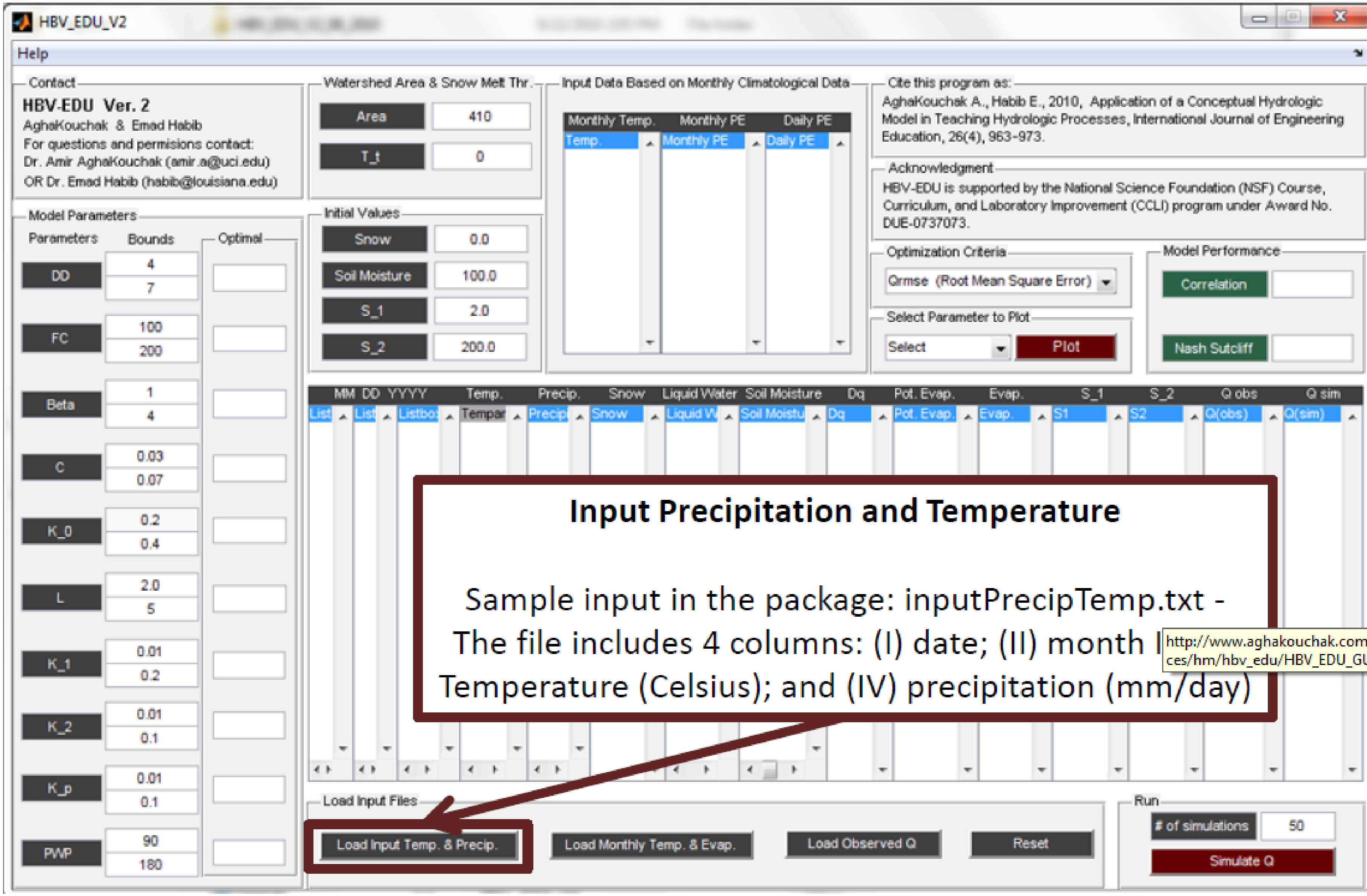
HBV-EDU


HBV_EDU_V2
Help
Contact
HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permisions contact:
Model Parameters
Parameters
Bounds
Optimal
DD
4
7
FC
100
200
Beta
1
4
C
0.03
0.07
K_0
0.2
0.4
L
2.0
5
K_1
0.01
0.2
K_2
0.01
0.1
K_p
0.01
0.1
PWP
90
180
Watershed Area & Snow Melt Thr.
Area
410
T_t
0
Initial Values
Snow
0.0
Soil Moisture
100.0
S_1
2.0
S_2
200.0
Input Data Based on Monthly Climatological Data
Monthly Temp.
Monthly PE
Daily PE
Cite this program as:
AghaKouchak A., Habib E., 2010, Application of a Conceptual Hydrologic Model in Teaching Hydrologic Processes, International Journal of Engineering Education, 26(4), 963-973.
Acknowledgment
HBV-EDU is supported by the National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement (CCLI) program under Award No. DUE-0737073.
Optimization Criteria
Qrmse (Root Mean Square Error)
Select Parameter to Plot
Select
Plot
Model Performance
Correlation
Nash Sutcliff
MM DD YYYY
Temp.
Precip.
Snow
Liquid Water
Soil Moisture
Dq
Pot. Evap.
Evap.
S_1
S_2
Q obs
Q sim
Lower Bound of parameter
http://www.aghakouchak.com/_/rsrc/ces/hm/hbv_edu/HBV_EDU_GUI.png
Load Input Files
Load Input Temp. & Precip.
Load Monthly Temp. & Evap.
Load Observed Q
Reset
Run
# of simulations
50
Simulate Q

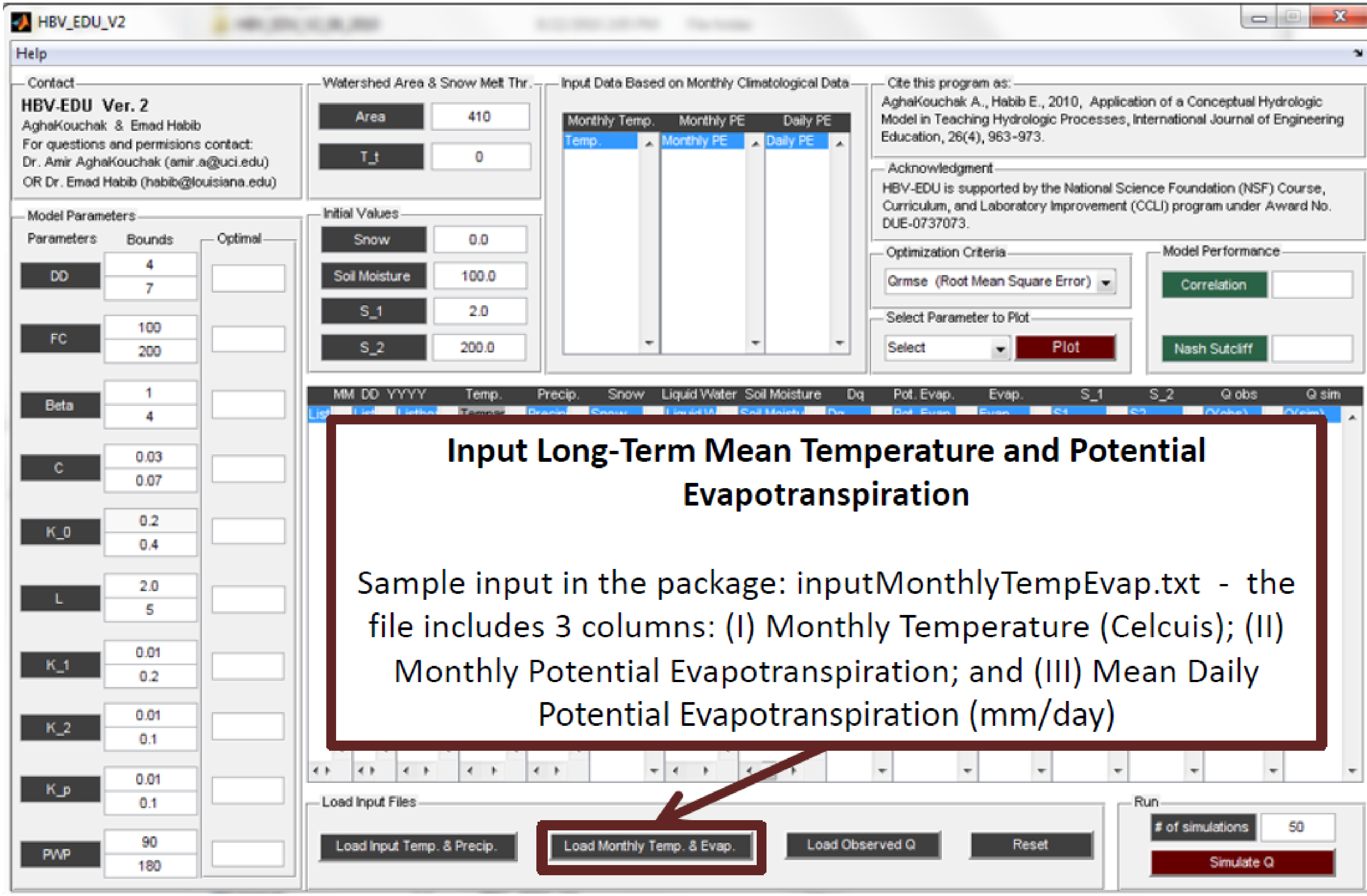
HBV-EDU


HBV_EDU_V2
Help
Contact
HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permisions contact:
Model Parameters
Parameters
Bounds
Optimal
DD
4
7
FC
100
200
Beta
1
4
C
0.03
0.07
K_0
0.2
0.4
L
2.0
5
K_1
0.01
0.2
K_2
0.01
0.1
K_p
0.01
0.1
PWP
90
180
Watershed Area & Snow Melt Thr.
Area
410
T_t
0
Initial Values
Snow
0.0
Soil Moisture
100.0
S_1
2.0
S_2
200.0
Input Data Based on Monthly Climatological Data
Monthly Temp.
Monthly PE
Daily PE
Cite this program as:
AghaKouchak A., Habib E., 2010, Application of a Conceptual Hydrologic Model in Teaching Hydrologic Processes, International Journal of Engineering Education, 26(4), 963-973.
Acknowledgment
HBV-EDU is supported by the National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement (CCLI) program under Award No. DUE-0737073.
Optimization Criteria
Qrmse (Root Mean Square Error)
Model Performance
Correlation
Select Parameter to Plot
Select
Plot
Nash Sutcliff
MM
DD
Temp.
Precip.
Snow
Liquid Water
Soil Moisture
Dq
Pot. Evap.
Evap.
S_1
S_2
Q obs
Q sim
Optimal Parameter
(after calibration)
Load Input Files
Load Input Temp. & Precip.
Load Monthly Temp. & Evap.
Load Observed Q
Reset
Run
# of simulations
50
Simulate Q

HBV-EDU


HBV_EDU_V2
Help
Contact
HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permisions contact:
Dr. Amir AghaKouchak (amir.a@uci.edu)
OR Dr. Emad Habib (habib@louisiana.edu)
Watershed Area & Snow Melt Thr.
Area 410
T_t 0
Input Data Based on Monthly Climatological Data
Monthly Temp. Monthly PE Daily PE
Cite this program as:
AghaKouchak A., Habib E., 2010, Application of a Conceptual Hydrologic Model in Teaching Hydrologic Processes, International Journal of Engineering Education, 26(4), 963-973.
Acknowledgment
HBV-EDU is supported by the National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement (CCLI) program under Award No. DUE-0737073.
Model Parameters
Parameters Bounds Optimal
DD 4 7
FC 100 200
Beta 1 4
C 0.03 0.07
K_0 0.2 0.4
L 2.0 5
K_1 0.01 0.2
K_2 0.01 0.1
K_p 0.01 0.1
PWP 90 180
Initial Values
Snow 0.0
Soil Moisture 100.0
S_1 2.0
S_2 200.0
Optimization Criteria
Qrmse (Root Mean Square Error)
Model Performance
Correlation
Nash Sutcliff
Select Parameter to Plot
Select
Plot
MM DD YYYY Temp. Precip. Snow Liquid Water Soil Moisture Dq Pot. Evap. Evap. S_1 S_2 Q obs Q sim
Input Precipitation and Temperature
Sample input in the package: inputPrecipTemp.txt -
The file includes 4 columns: (I) date; (II) month
Temperature (Celsius); and (IV) precipitation (mm/day)
http://www.aghakouchak.com/_
ces/hm/hbv_edu/HBV_EDU_GUI.
Load Input Files
Load Input Temp. & Precip.
Load Monthly Temp. & Evap.
Load Observed Q
Reset
Run
# of simulations 50
Simulate Q

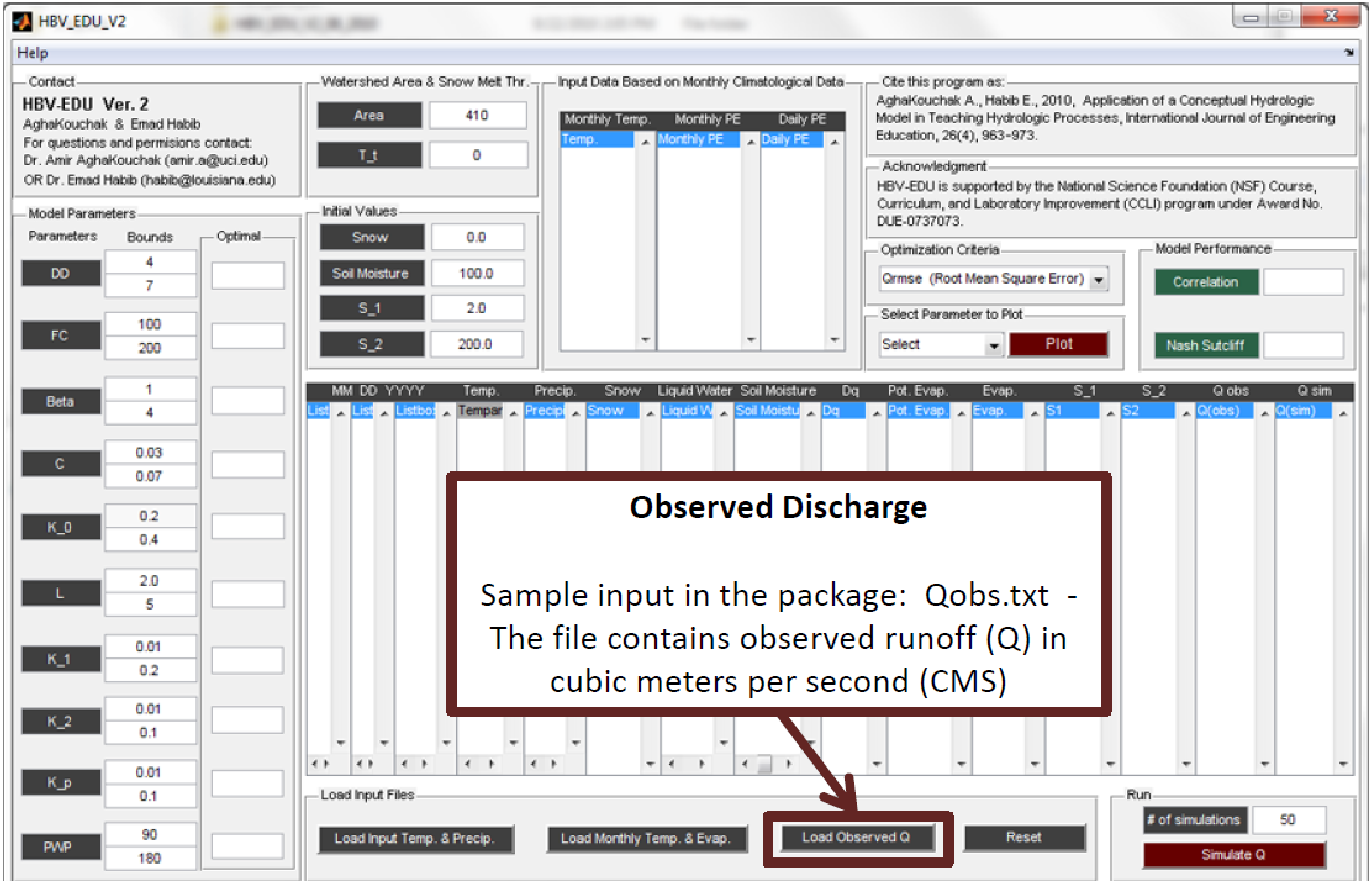
HBV-EDU



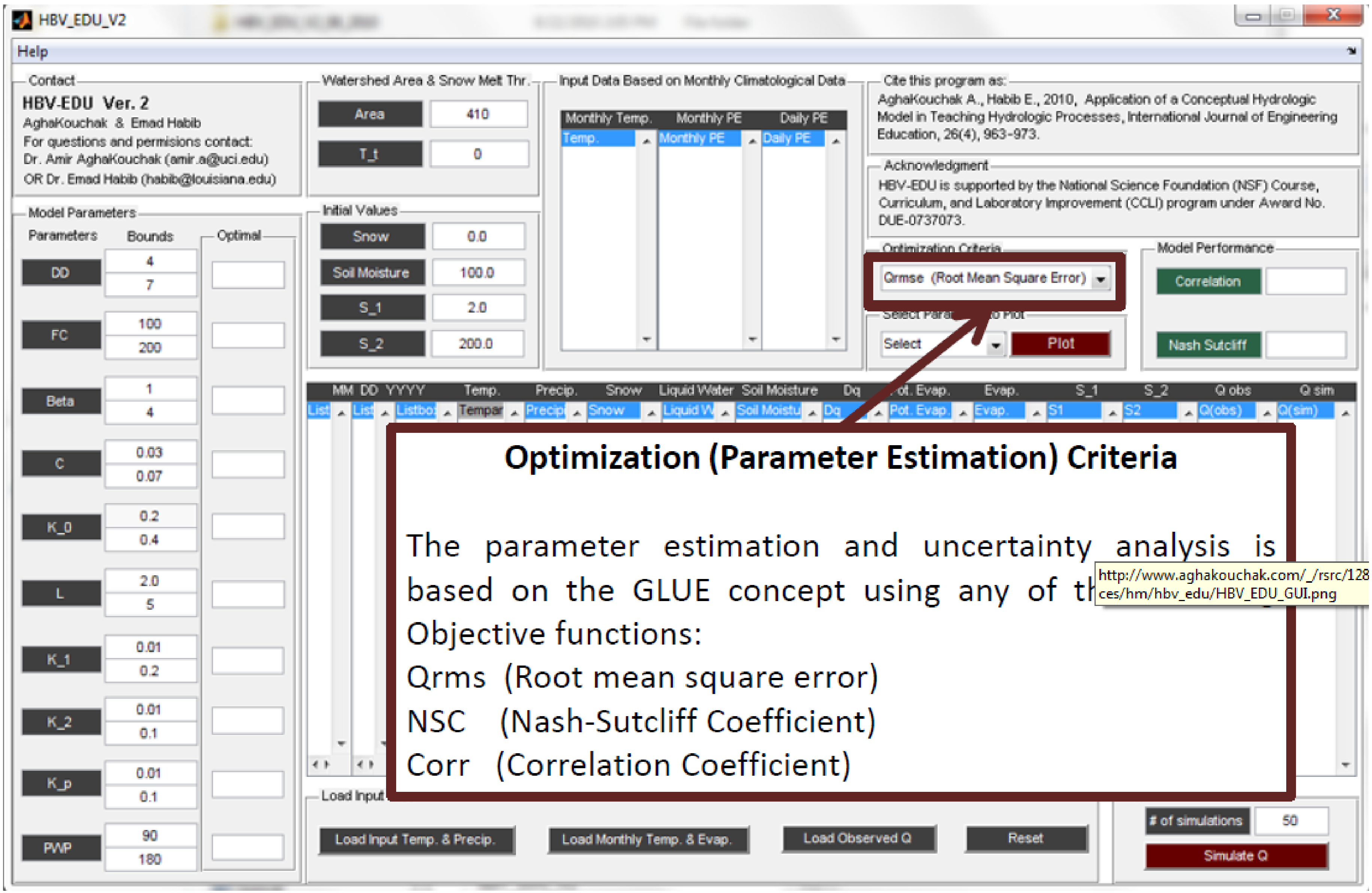
Input Long-Term Mean Temperature and Potential Evapotranspiration

Sample input in the package: inputMonthlyTempEvap.txt - the file includes 3 columns: (I) Monthly Temperature (Celcuis); (II) Monthly Potential Evapotranspiration; and (III) Mean Daily Potential Evapotranspiration (mm/day)

HBV-EDU


HBV_EDU_V2
Help
Contact
HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permisions contact:
Dr. Amir AghaKouchak (amir.a@uci.edu)
OR Dr. Emad Habib (habib@louisiana.edu)
Watershed Area & Snow Melt Thr.
Area
410
T_t
0
Input Data Based on Monthly Climatological Data
Monthly Temp.
Monthly PE
Daily PE
Cite this program as:
AghaKouchak A., Habib E., 2010, Application of a Conceptual Hydrologic Model in Teaching Hydrologic Processes, International Journal of Engineering Education, 26(4), 963-973.
Acknowledgment
HBV-EDU is supported by the National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement (CCLI) program under Award No. DUE-0737073.
Model Parameters
Parameters
Bounds
Optimal
DD
4
7
FC
100
200
Beta
1
4
C
0.03
0.07
K_0
0.2
0.4
L
2.0
5
K_1
0.01
0.2
K_2
0.01
0.1
K_p
0.01
0.1
PWP
90
180
Initial Values
Snow
0.0
Soil Moisture
100.0
S_1
2.0
S_2
200.0
Optimization Criteria
Qrmse (Root Mean Square Error)
Select Parameter to Plot
Select
Plot
Model Performance
Correlation
Nash Sutcliff
MM DD YYYY Temp. Precip. Snow Liquid Water Soil Moisture Dq Pot. Evap. Evap. S_1 S_2 Q obs Q sim
Observed Discharge
Sample input in the package: Qobs.txt - The file contains observed runoff (Q) in cubic meters per second (CMS)
Load Input Files
Load Input Temp. & Precip.
Load Monthly Temp. & Evap.
Load Observed Q
Reset
Run
# of simulations
50
Simulate Q

HBV-EDU



Optimization (Parameter Estimation) Criteria

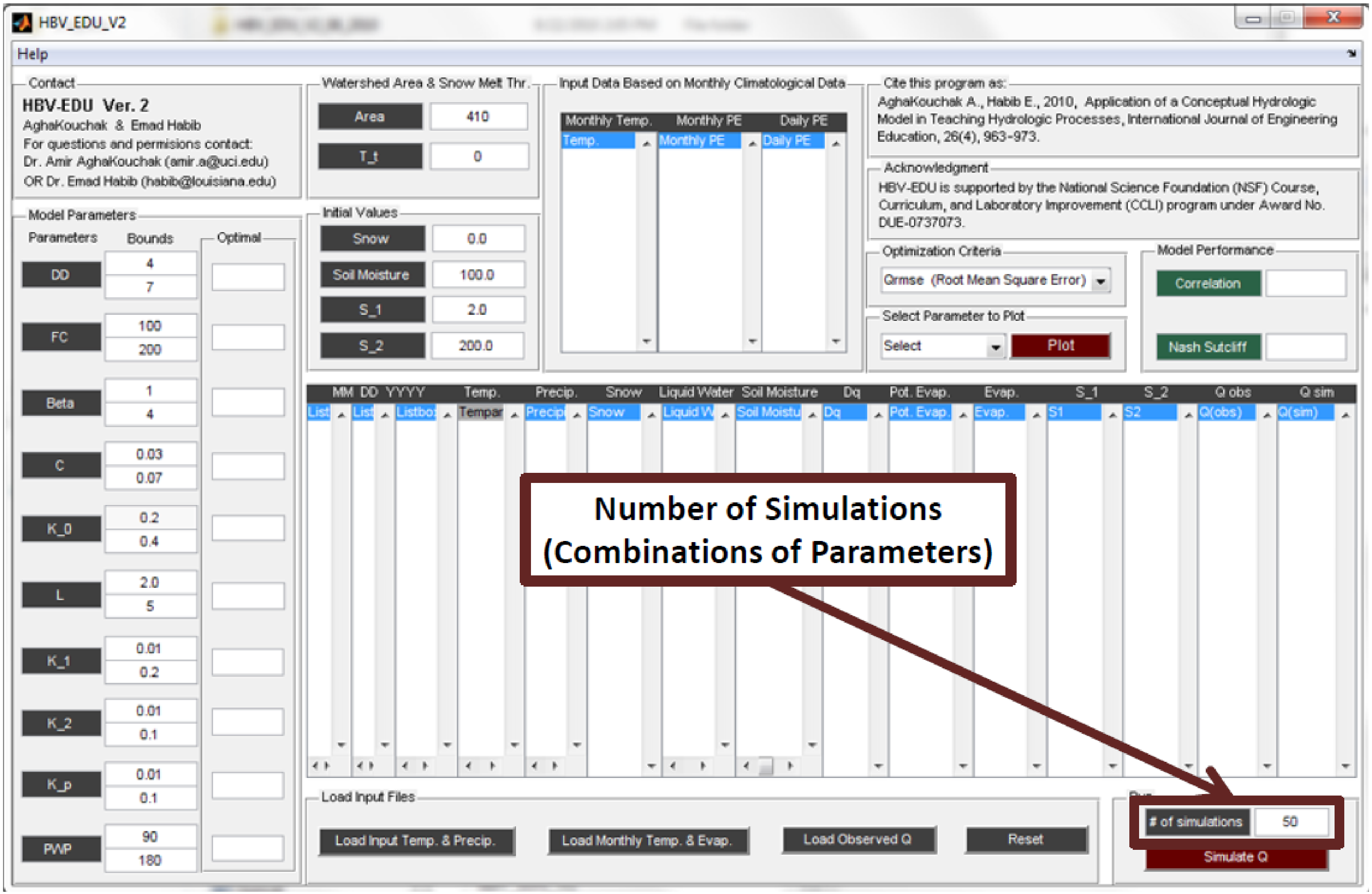
The parameter estimation and uncertainty analysis is based on the GLUE concept using any of th[e following]
Objective functions:

Qrms (Root mean square error)

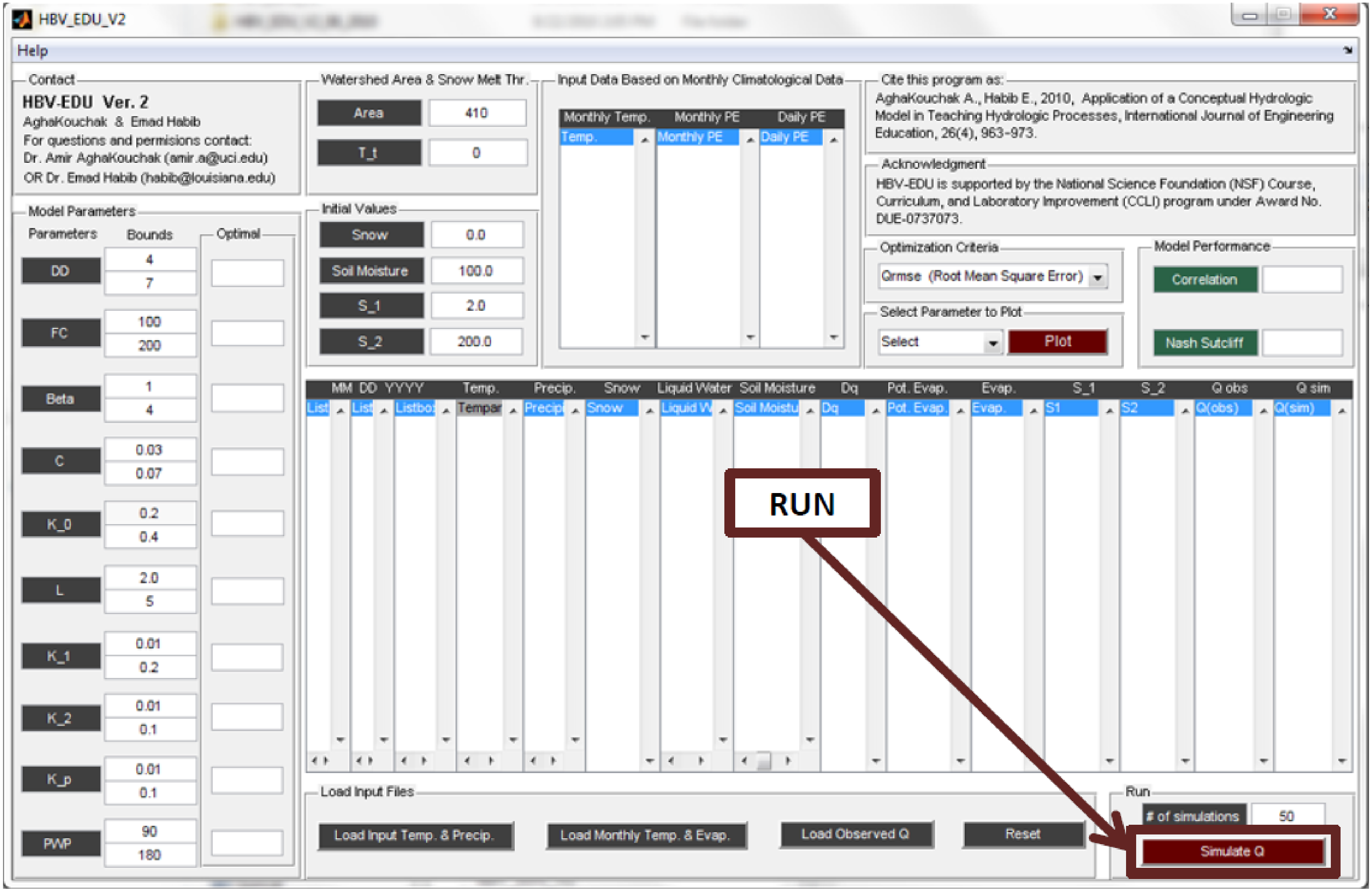
NSC (Nash-Sutcliff Coefficient)

Corr (Correlation Coefficient)

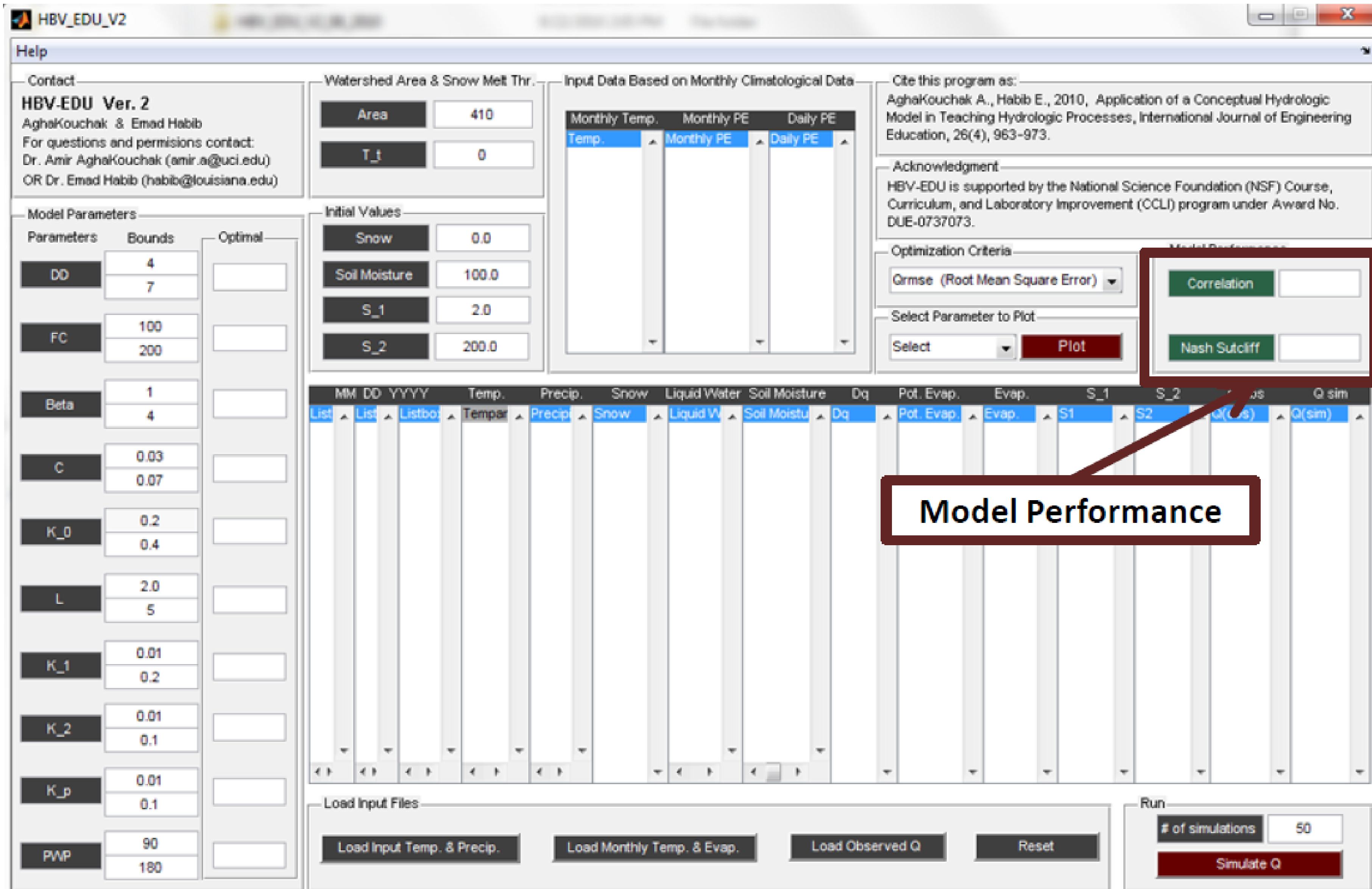
HBV-EDU


HBV_EDU_V2
Help
Contact
HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permisions contact:
Dr. Amir AghaKouchak (amir.a@uci.edu)
OR Dr. Emad Habib (habib@louisiana.edu)
Watershed Area & Snow Melt Thr.
Area 410
T_t 0
Input Data Based on Monthly Climatological Data
Monthly Temp. Monthly PE Daily PE
Cite this program as:
AghaKouchak A., Habib E., 2010, Application of a Conceptual Hydrologic Model in Teaching Hydrologic Processes, International Journal of Engineering Education, 26(4), 963-973.
Acknowledgment
HBV-EDU is supported by the National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement (CCLI) program under Award No. DUE-0737073.
Model Parameters
Parameters Bounds Optimal
DD 4 7
FC 100 200
Beta 1 4
C 0.03 0.07
K_0 0.2 0.4
L 2.0 5
K_1 0.01 0.2
K_2 0.01 0.1
K_p 0.01 0.1
PWP 90 180
Initial Values
Snow 0.0
Soil Moisture 100.0
S_1 2.0
S_2 200.0
Optimization Criteria
Qrmse (Root Mean Square Error)
Select Parameter to Plot
Select
Plot
Model Performance
Correlation
Nash Sutcliff
MM DD YYYY Temp. Precip. Snow Liquid Water Soil Moisture Dq Pot. Evap. Evap. S_1 S_2 Q obs Q sim
Number of Simulations (Combinations of Parameters)
Load Input Files
Load Input Temp. & Precip.
Load Monthly Temp. & Evap.
Load Observed Q
Reset
# of simulations 50
Simulate Q

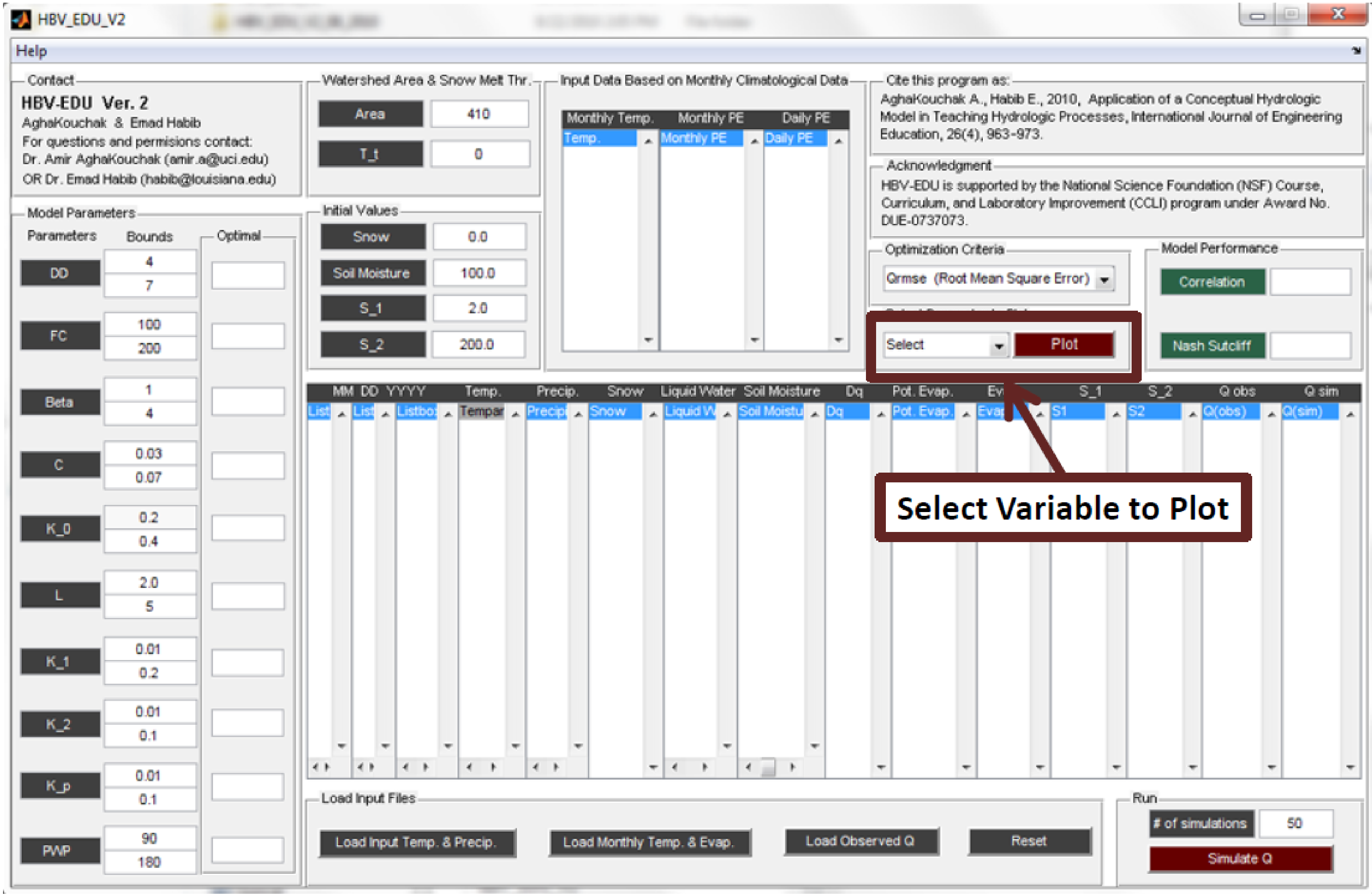
HBV-EDU


HBV_EDU_V2
Help
Contact
HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permisions contact:
Dr. Amir AghaKouchak (amir.a@uci.edu)
OR Dr. Emad Habib (habib@louisiana.edu)
Watershed Area & Snow Melt Thr.
Area 410
T_t 0
Input Data Based on Monthly Climatological Data
Monthly Temp. Monthly PE Daily PE
Cite this program as:
AghaKouchak A., Habib E., 2010, Application of a Conceptual Hydrologic Model in Teaching Hydrologic Processes, International Journal of Engineering Education, 26(4), 963-973.
Acknowledgment
HBV-EDU is supported by the National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement (CCLI) program under Award No. DUE-0737073.
Model Parameters
Parameters Bounds Optimal
DD 4 7
FC 100 200
Beta 1 4
C 0.03 0.07
K_0 0.2 0.4
L 2.0 5
K_1 0.01 0.2
K_2 0.01 0.1
K_p 0.01 0.1
PWP 90 180
Initial Values
Snow 0.0
Soil Moisture 100.0
S_1 2.0
S_2 200.0
Optimization Criteria
Qrmse (Root Mean Square Error)
Model Performance
Correlation
Nash Sutcliff
Select Parameter to Plot
Select
Plot
MM DD YYYY Temp. Precip. Snow Liquid Water Soil Moisture Dq Pot. Evap. Evap. S_1 S_2 Q obs Q sim
RUN
Load Input Files
Load Input Temp. & Precip.
Load Monthly Temp. & Evap.
Load Observed Q
Reset
Run
# of simulations 50
Simulate Q

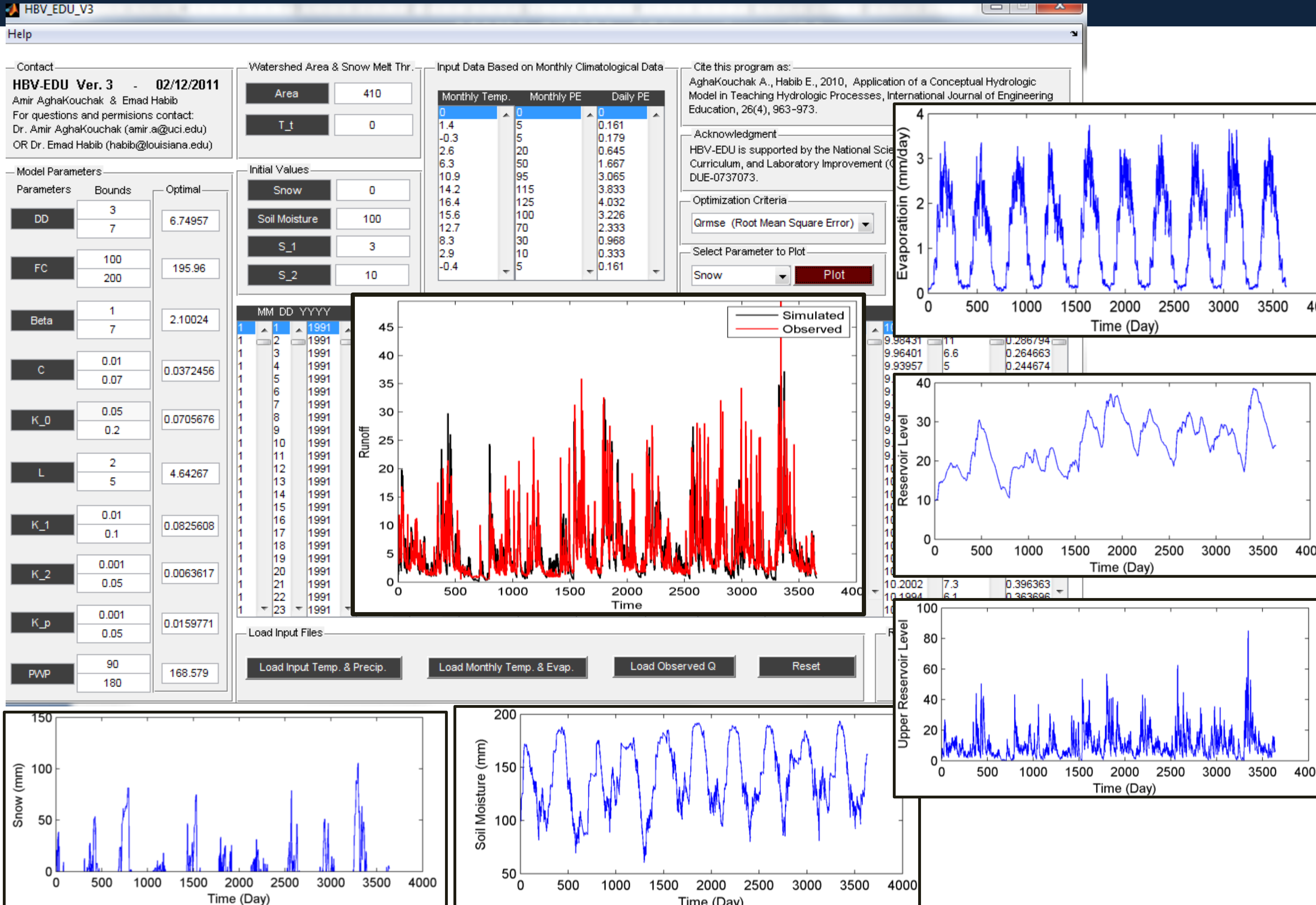
HBV-EDU


HBV_EDU_V2
Help
Contact
HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permisions contact:
Dr. Amir AghaKouchak (amir.a@uci.edu)
OR Dr. Emad Habib (habib@louisiana.edu)
Watershed Area & Snow Melt Thr.
Area 410
T_t 0
Input Data Based on Monthly Climatological Data
Monthly Temp. Monthly PE Daily PE
Cite this program as:
AghaKouchak A., Habib E., 2010, Application of a Conceptual Hydrologic Model in Teaching Hydrologic Processes, International Journal of Engineering Education, 26(4), 963-973.
Acknowledgment
HBV-EDU is supported by the National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement (CCLI) program under Award No. DUE-0737073.
Model Parameters
Parameters Bounds Optimal
DD 4 7
FC 100 200
Beta 1 4
C 0.03 0.07
K_0 0.2 0.4
L 2.0 5
K_1 0.01 0.2
K_2 0.01 0.1
K_p 0.01 0.1
PWP 90 180
Initial Values
Snow 0.0
Soil Moisture 100.0
S_1 2.0
S_2 200.0
Optimization Criteria
Qrmse (Root Mean Square Error)
Select Parameter to Plot
Select
Plot
Correlation
Nash Sutcliff
MM DD YYYY Temp. Precip. Snow Liquid Water Soil Moisture Dq Pot. Evap. Evap. S_1 S_2 Q sim
Model Performance
Load Input Files
Load Input Temp. & Precip.
Load Monthly Temp. & Evap.
Load Observed Q
Reset
Run
# of simulations 50
Simulate Q

HBV-EDU


HBV_EDU_V2
Help
Contact
HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permisions contact:
Dr. Amir AghaKouchak (amir.a@uci.edu)
OR Dr. Emad Habib (habib@louisiana.edu)
Watershed Area & Snow Melt Thr.
Area 410
T_t 0
Input Data Based on Monthly Climatological Data
Monthly Temp. Monthly PE Daily PE
Cite this program as:
AghaKouchak A., Habib E., 2010, Application of a Conceptual Hydrologic Model in Teaching Hydrologic Processes, International Journal of Engineering Education, 26(4), 963-973.
Acknowledgment
HBV-EDU is supported by the National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement (CCLI) program under Award No. DUE-0737073.
Model Parameters
Parameters Bounds Optimal
DD 4 7
FC 100 200
Beta 1 4
C 0.03 0.07
K_0 0.2 0.4
L 2.0 5
K_1 0.01 0.2
K_2 0.01 0.1
K_p 0.01 0.1
PWP 90 180
Initial Values
Snow 0.0
Soil Moisture 100.0
S_1 2.0
S_2 200.0
Optimization Criteria
Qrmse (Root Mean Square Error)
Model Performance
Correlation
Nash Sutcliff
Select
Plot
MM DD YYYY Temp. Precip. Snow Liquid Water Soil Moisture Dq Pot. Evap. Ev S_1 S_2 Q obs Q sim
Select Variable to Plot
Load Input Files
Load Input Temp. & Precip.
Load Monthly Temp. & Evap.
Load Observed Q
Reset
Run
# of simulations 50
Simulate Q

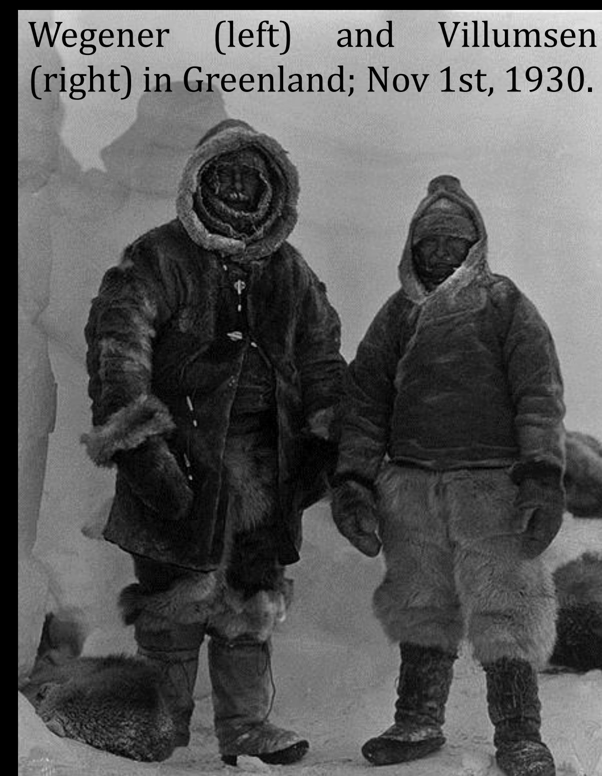
HBV-EDU (Version 3)



Alfred Wegener (1880 – 1930)

Famous hydrologist, meteorologist and interdisciplinary scientist Alfred Wegener was born in Berlin, Germany in November of 1880 He created the first balloons that were used to track weather and air masses. In order to better study the circulation of polar air, Wegener was part of several expeditions that went to Greenland. He and a companion went missing in November of 1930 on a Greenland expedition. Wegener's body was not found until May of 1931 (Sources: wikipedia.org & about.com).

"...Wegener and Villumsen took two dog sleds and made for West camp. They took no food for the dogs and killed them to feed the rest until they could only run one sled. They never reached the camp."



Wegener (left) and Villumsen (right) in Greenland; Nov 1st, 1930.

Vehicles used by the 1930 expedition

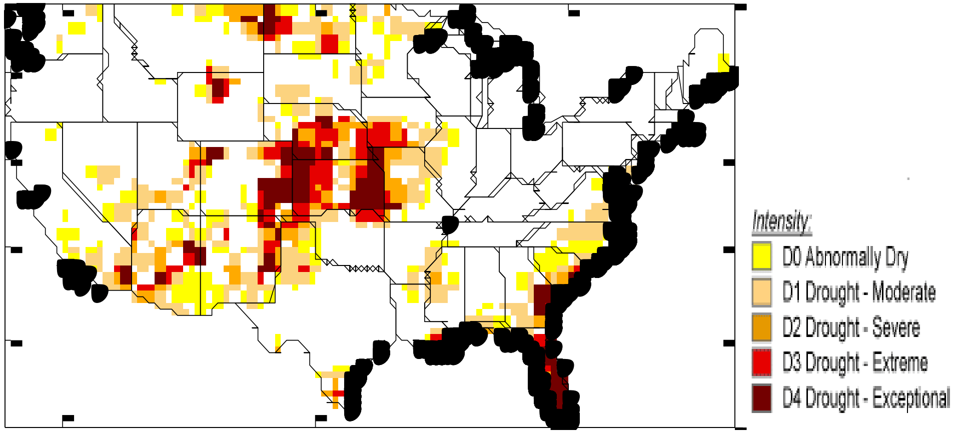
GIDMaPS: Global Integrated Drought Monitoring and Prediction System

Multi-Index Drought Monitoring

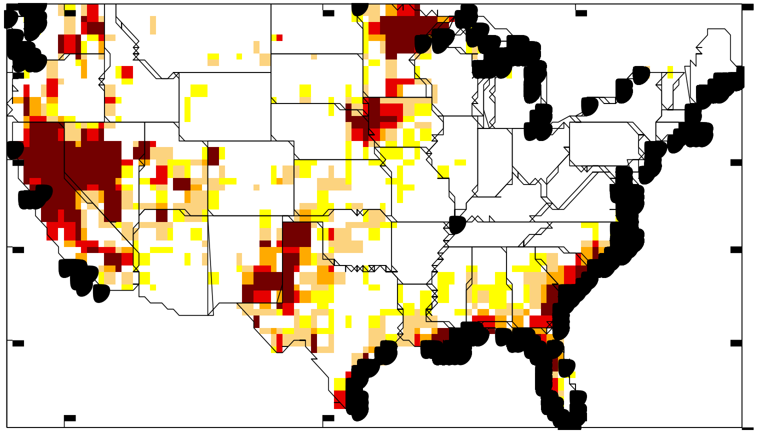
Different drought indices based on different climate variables (e.g., Precipitation, soil moisture):

- Standardized Precipitation Index (SPI)
- Standardized Soil Moisture Index (SSI)
- Standardized runoff Index (SRI)
- Palmer Drought Severity Index (PDSI)

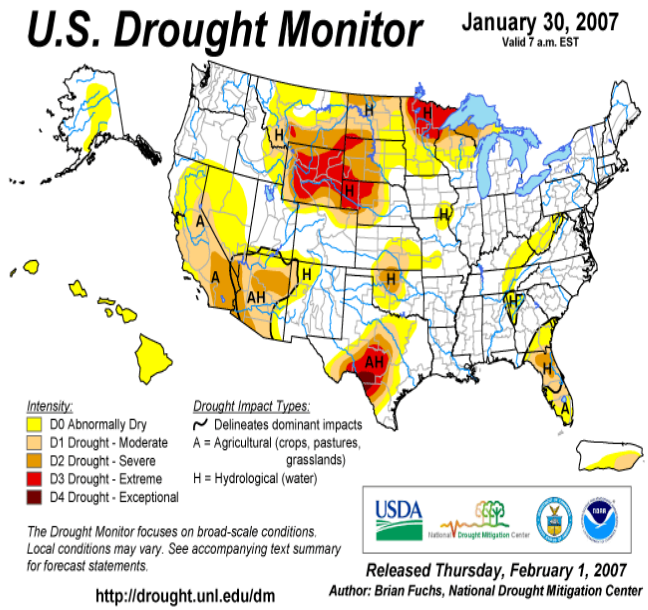
SPI 2012-1



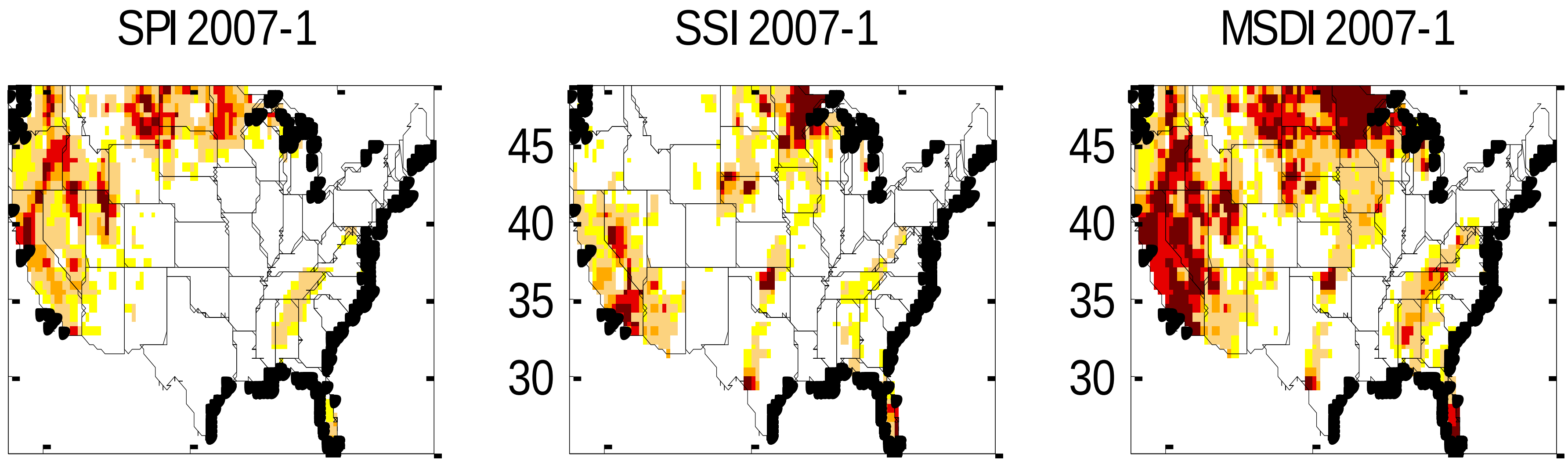
SSI 2012-1



Multi-Index Drought Monitoring

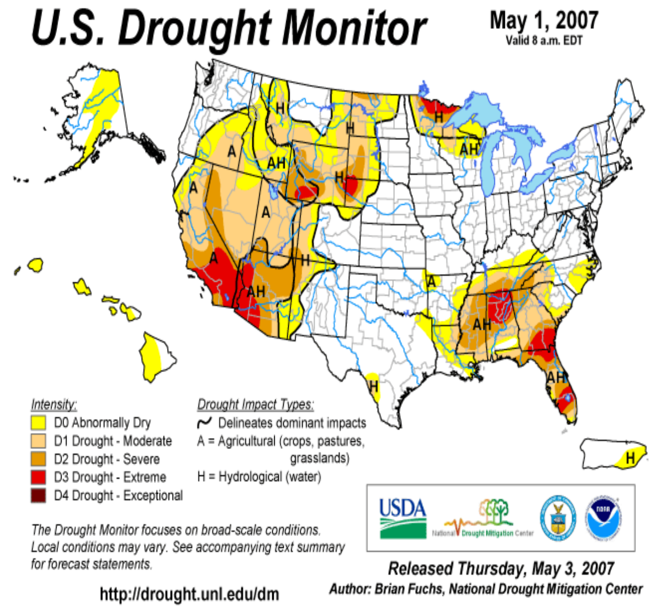


1-Month SPI and SSI Derived Using NASA MERRA-LAND Precipitation and soil moisture Data.

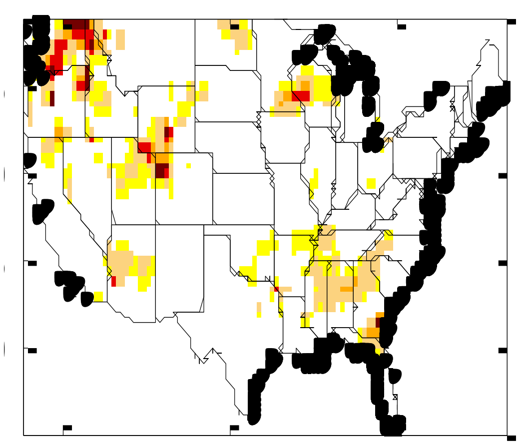


Multi-Index Drought Monitoring

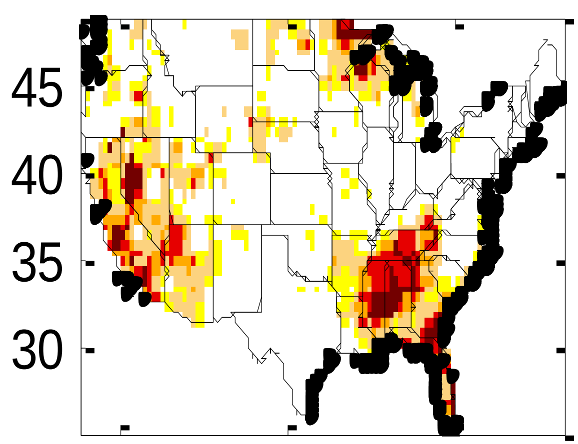
1-Month SPI and SSI Derived Using NASA MERRA-LAND Precipitation and soil moisture Data.



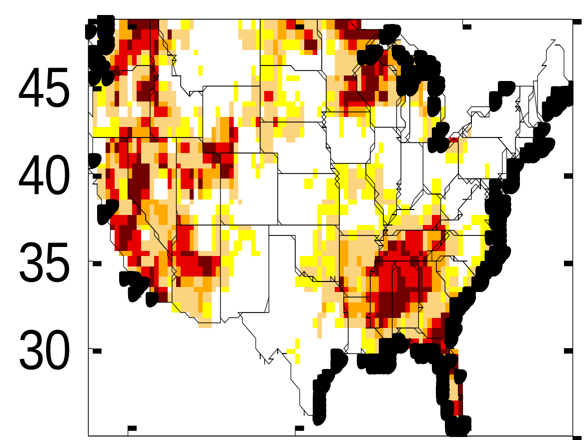
SPI 2007-4



SSI 2007-4

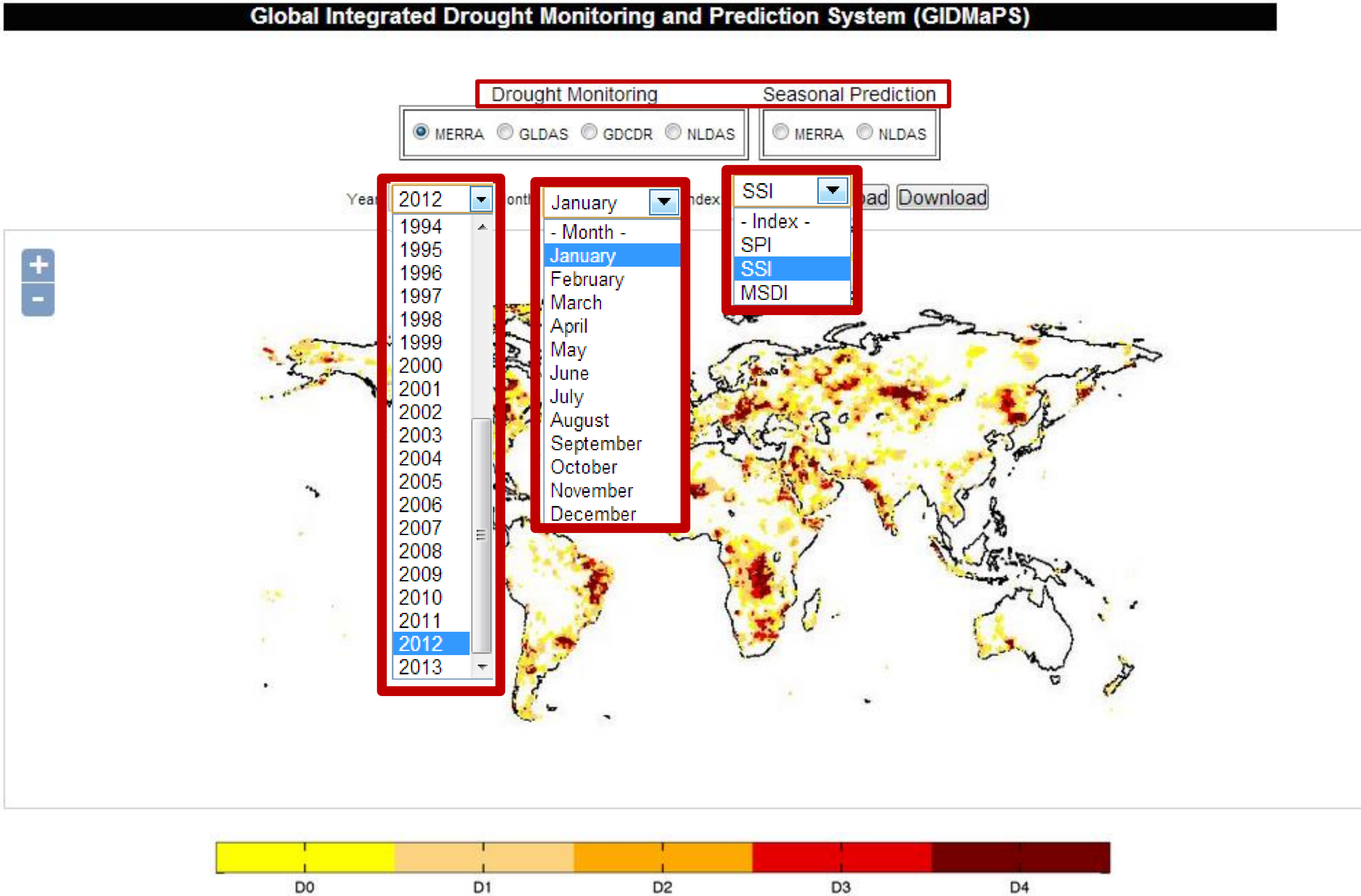


MSDI 2007-4



GIDMaPS: Global Integrated Drought Monitoring and Prediction System

http://drought.eng.uci.edu/



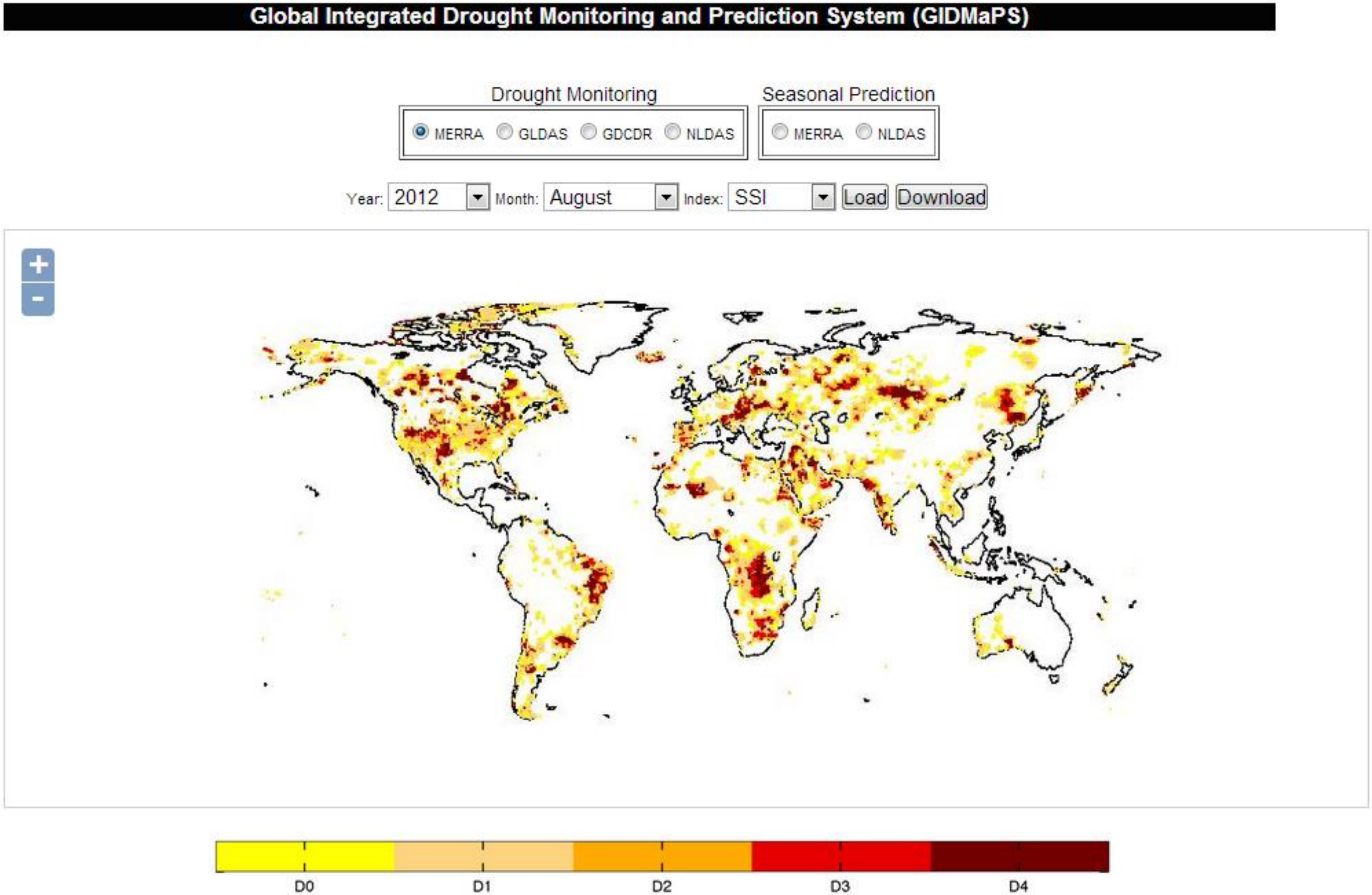
GIDMaPS: Global Integrated Drought Monitoring and Prediction System

Input Data Set	ID	Source	Resolution
NASA Modern-Era Retrospective analysis for Research and Applications – Reichle et al., 2011 - Precipitation and Soil Moisture	MERRA	NASA	2/3°x 1/2°
North American Land Data Assimilation System - Kumar et al., 2006 - Precipitation and Soil Moisture	NLDAS	NASA	0.125 °
Global Drought Climate Data Record - AghaKouchak and Nakhjiri, 2012 – Precipitation – combines real-time PERSIANN satellite data (Sorooshian et al., 2000; Hsu et al., 1997) with long-term GPCP (Adler et al., 2001) observations.	GDCDR	UCI	0.5°
Global Land Data Assimilation System (GLDAS) - Peters-Lidard et al., 2007 - Precipitation and Soil Moisture	GLDAS	NASA	1°

Drought Indicator	ID	Reference
Standardized Precipitation Index	SPI	McKee et al., 1993
Standardized Soil Moisture Index	SSI	Hao and AghaKouchak, 2013a
Multivariate Standardized Drought Index	MSDI	Hao and AghaKouchak, 2013a,b

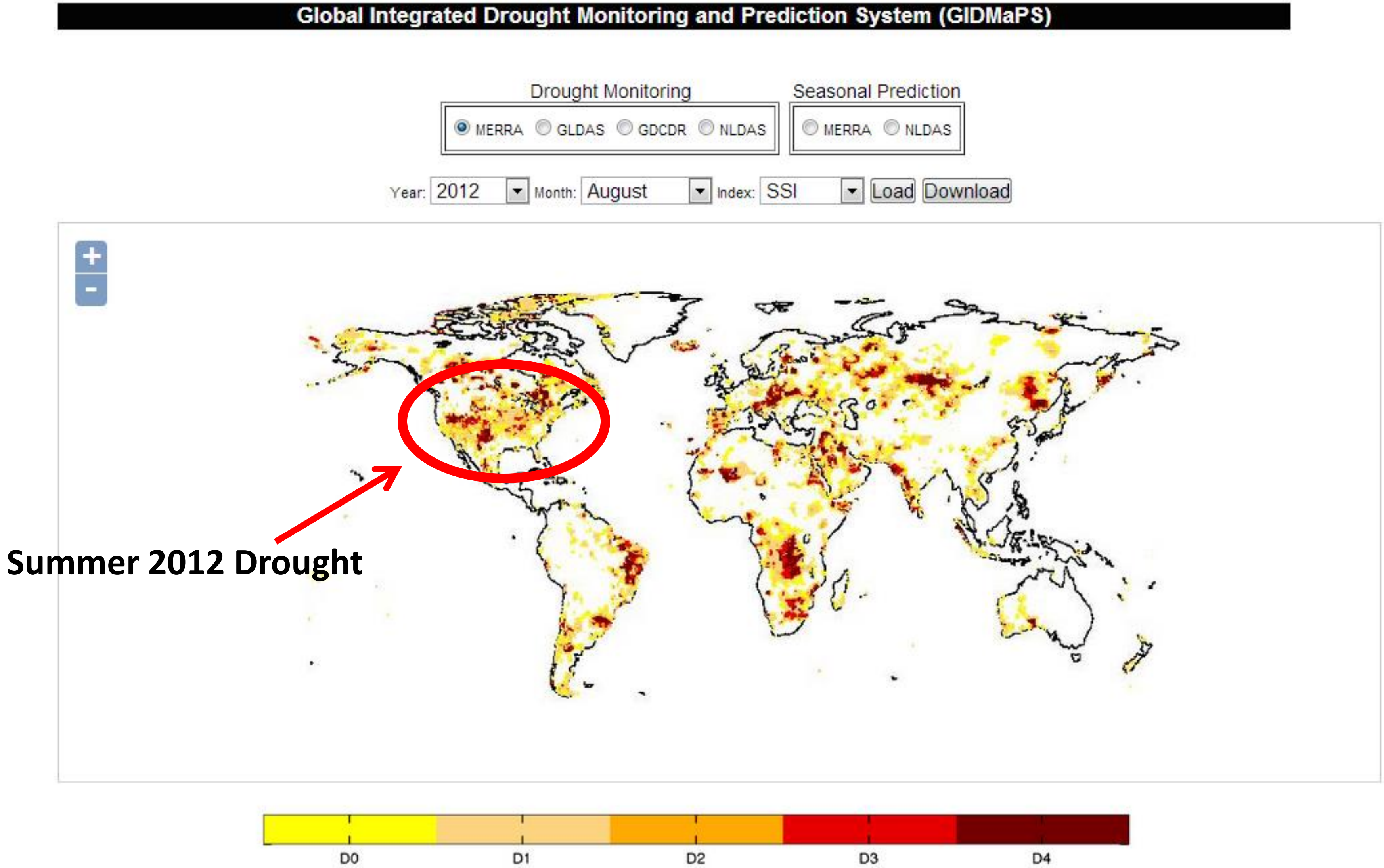
GIDMaPS: Global Integrated Drought Monitoring and Prediction System

http://drought.eng.uci.edu/index.html



GIDMaPS: Global Integrated Drought Monitoring and Prediction System

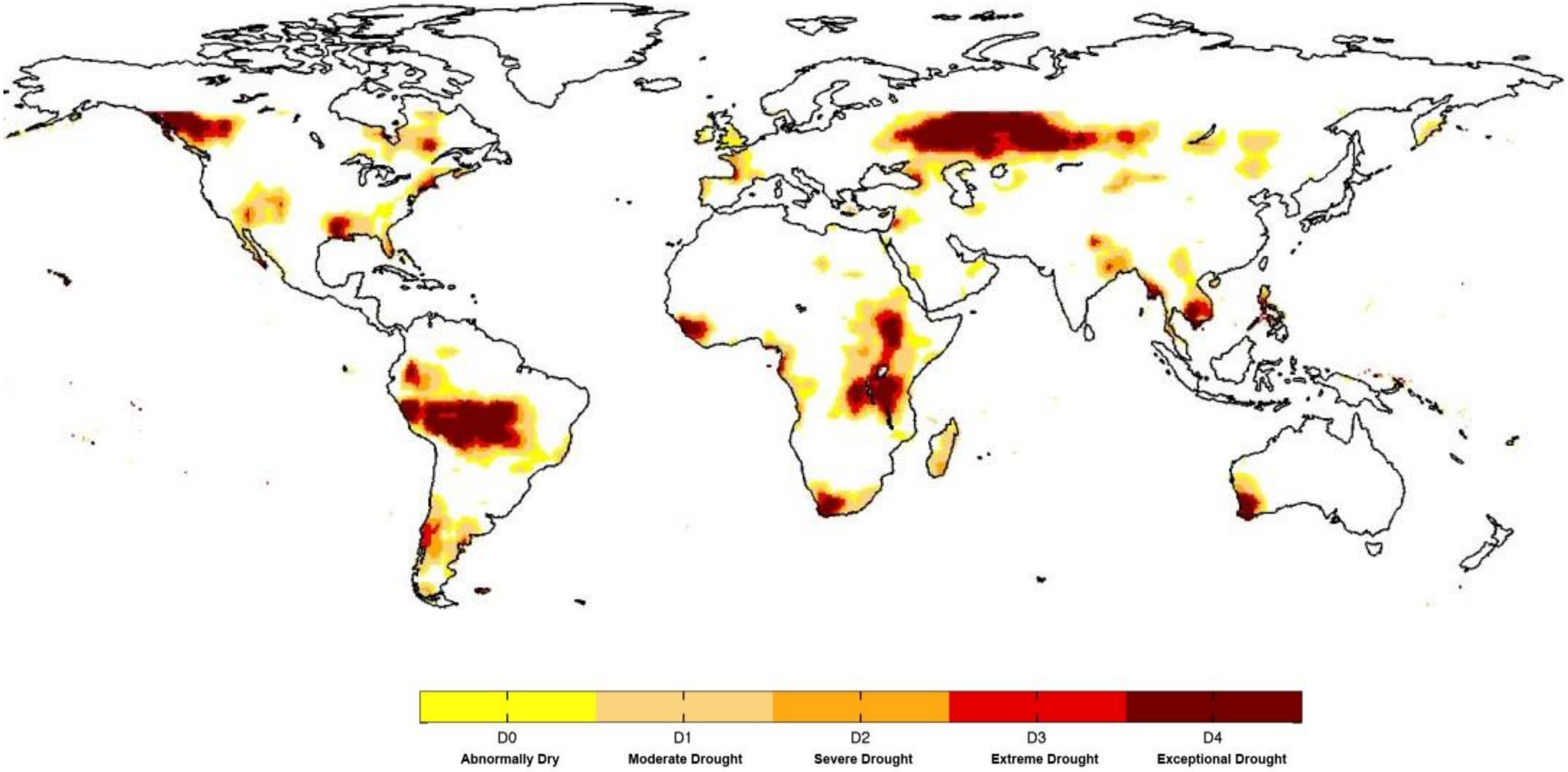
http://drought.eng.uci.edu/index.html



GIDMaPS: Global Integrated Drought Monitoring and Prediction System

http://drought.eng.uci.edu/

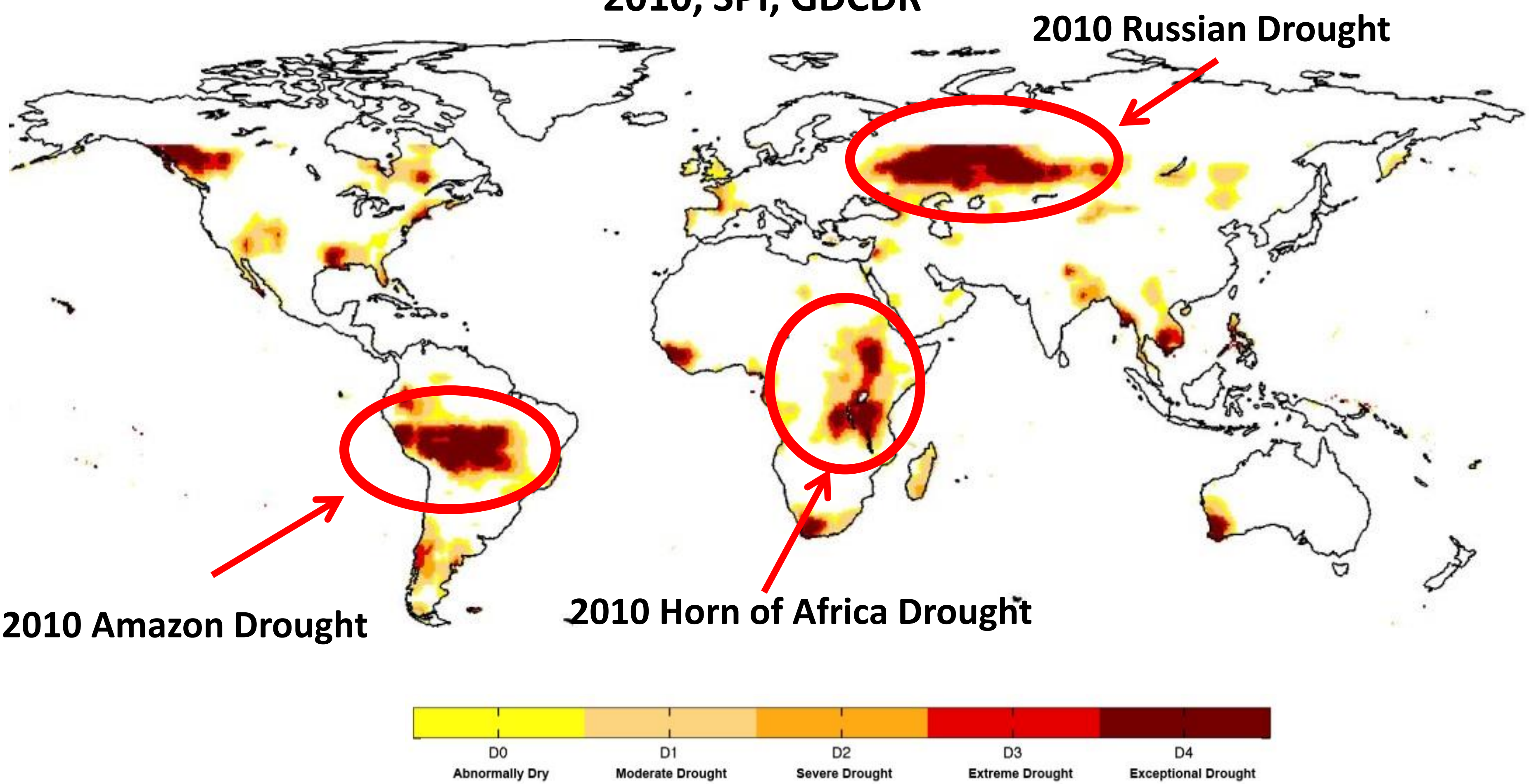
2010, SPI, GDCDR (PERSIANN combined with GPCP)



GIDMaPS: Global Integrated Drought Monitoring and Prediction System

http://drought.eng.uci.edu/

2010, SPI, GDCDR



GIDMaPS: Global Integrated Drought Monitoring and Prediction System

Prediction component is based on a drought persistence model which requires historical observations. The seasonal drought prediction component is based on two input data sets (MERRA and NLDAS) and three drought indicators (SPI, SSI and MSDI).

$$A_{i+1}(1) = S_{i-4} + S_{i-3} + S_{i-2} + S_{i-1} + S_i + S(1)_{i+1}$$

$$A_{i+1}(2) = S_{i-4} + S_{i-3} + S_{i-2} + S_{i-1} + S_i + S(2)_{i+1}$$

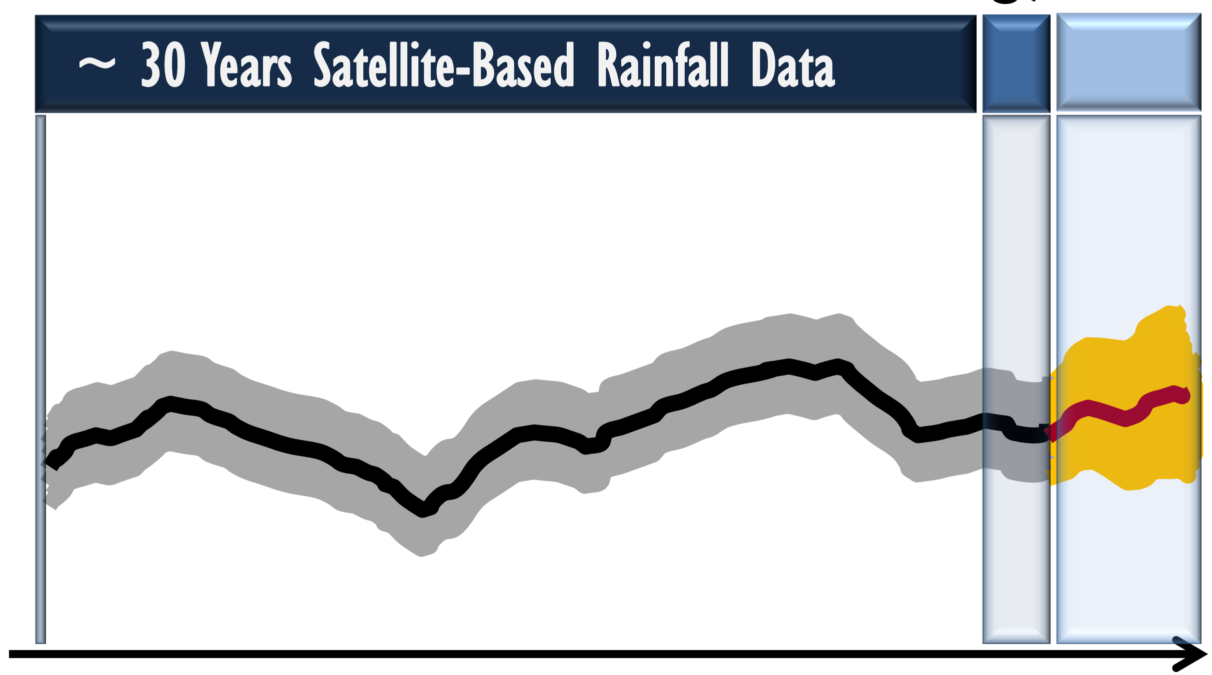
......

$$A_{i+1}(m) = S_{i-4} + S_{i-3} + S_{i-2} + S_{i-1} + S_i + S(m)_{i+1}$$

IOP PUBLISHING ENVIRONMENTAL RESEARCH LETTERS
Environ. Res. Lett. 7 (2012) 044037 (8pp) doi:10.1088/1748-9326/7/4/044037

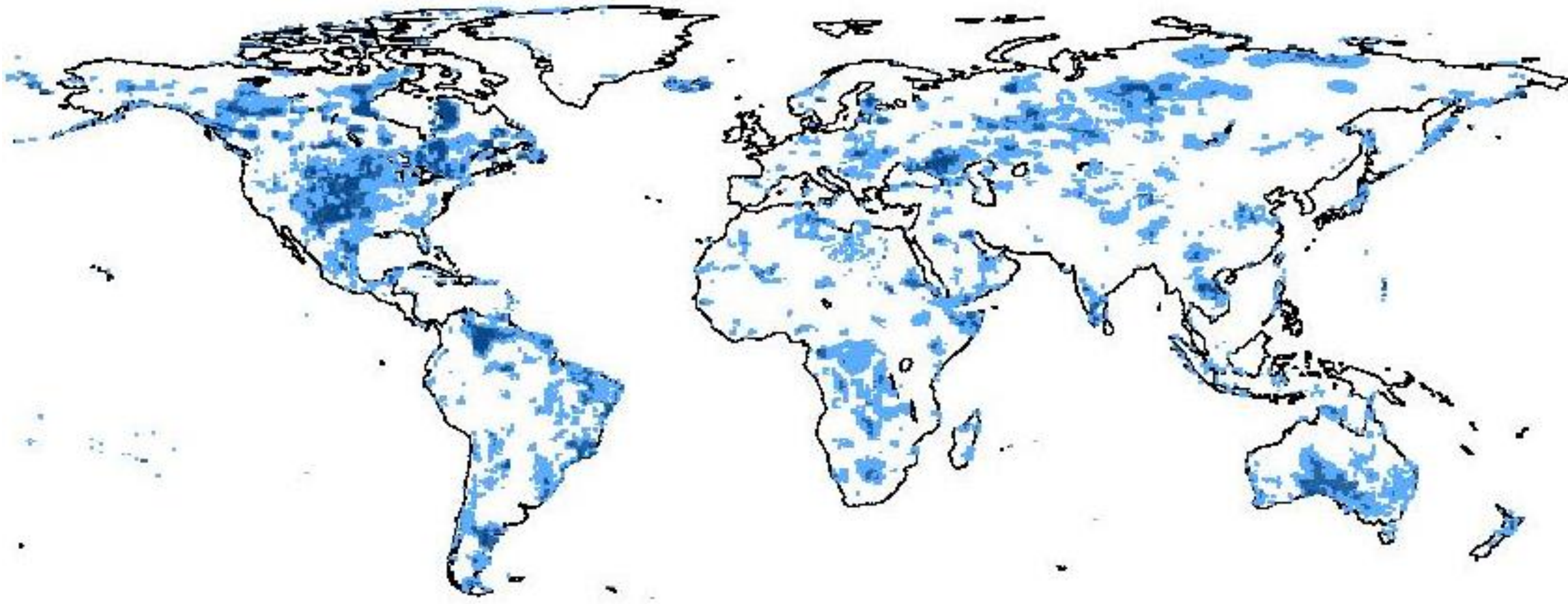
A near real-time satellite-based global drought climate data record

Amir AghaKouchak and Navid Nakhjiri
University of California Irvine, E4130 Engineering Gateway Irvine, CA 92697, USA
E-mail: amir.a@uci.edu and nnakhjir@uci.edu



GIDMaPS: Global Integrated Drought Monitoring and Prediction System

March 2013

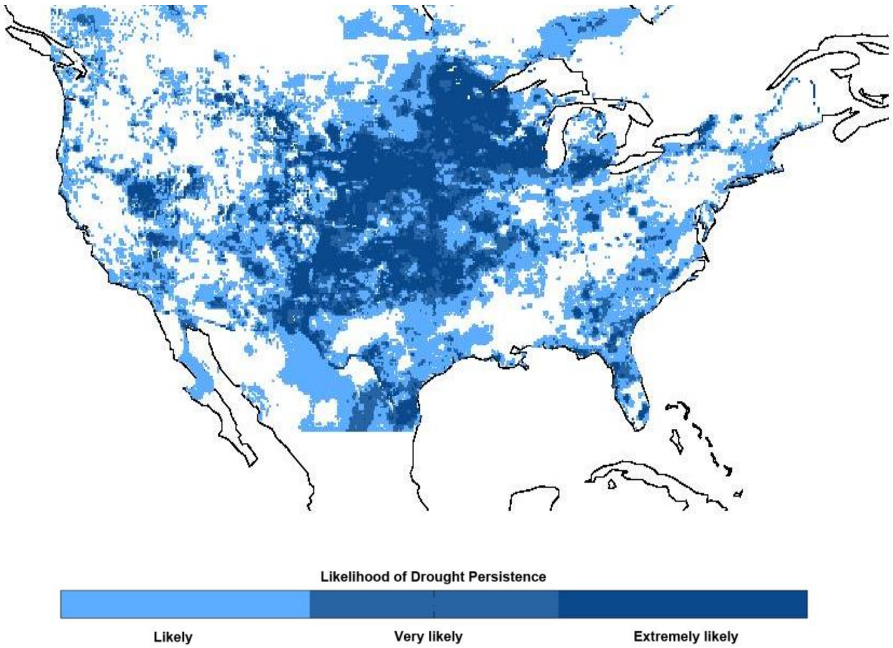


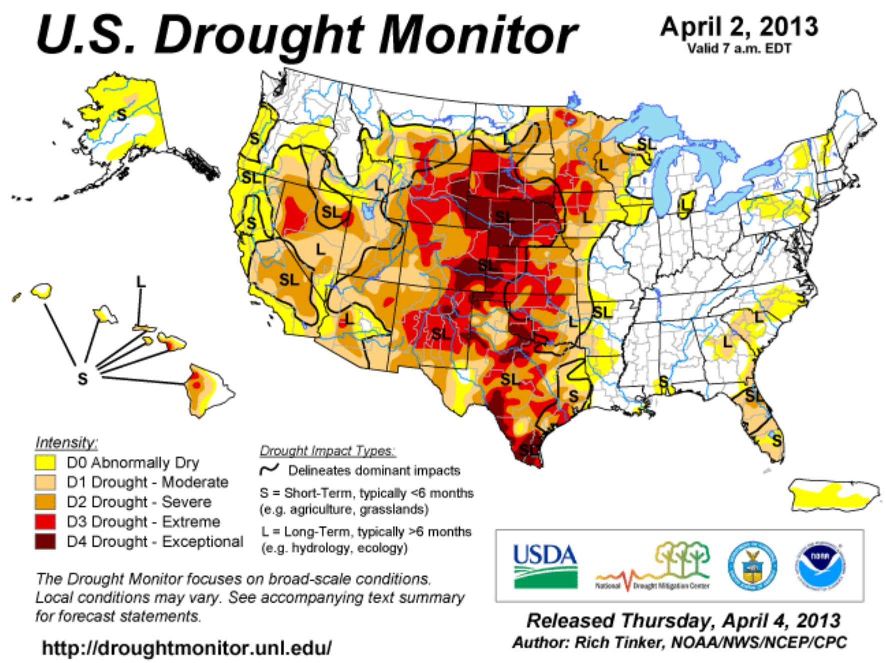
Likelihood of Drought Persistence

Likely | Very likely | Extremely likely

GIDMaPS: Global Integrated Drought Monitoring and Prediction System

March 31, 2013





The probability values of the drought prediction component are converted to a 3-catergory drought likelihood measure:
(a) drought likely to persist (≥70% probability)
(b) drought very likely to persist (≥90% probability)
(a) drought extremely likely to persist (≥95% probability)

Validation Toolbox:

Evaluation of Climate and Remote Sensing Data

Validation Toolbox

http://amir.eng.uci.edu/downloads/ValidationToolbox.zip

Performance Metrics for Evaluation of Remote Sensing Observations and Climate Model Simulations: A simple and easy to use Validation Toolbox (MATLAB source code) that can be used for validation of gridded data including satellite observations, reanalysis data, and weather and climate model simulations. In addition to the commonly used categorical indices, the toolbox includes the Volumetric Hit Index (VHI), Volumetric False Alarm Ration (VFAR), Volumetric Missed Index (VMI), and Volumetric Critical Success Index (VCSI).