

Integrated Water Cycle

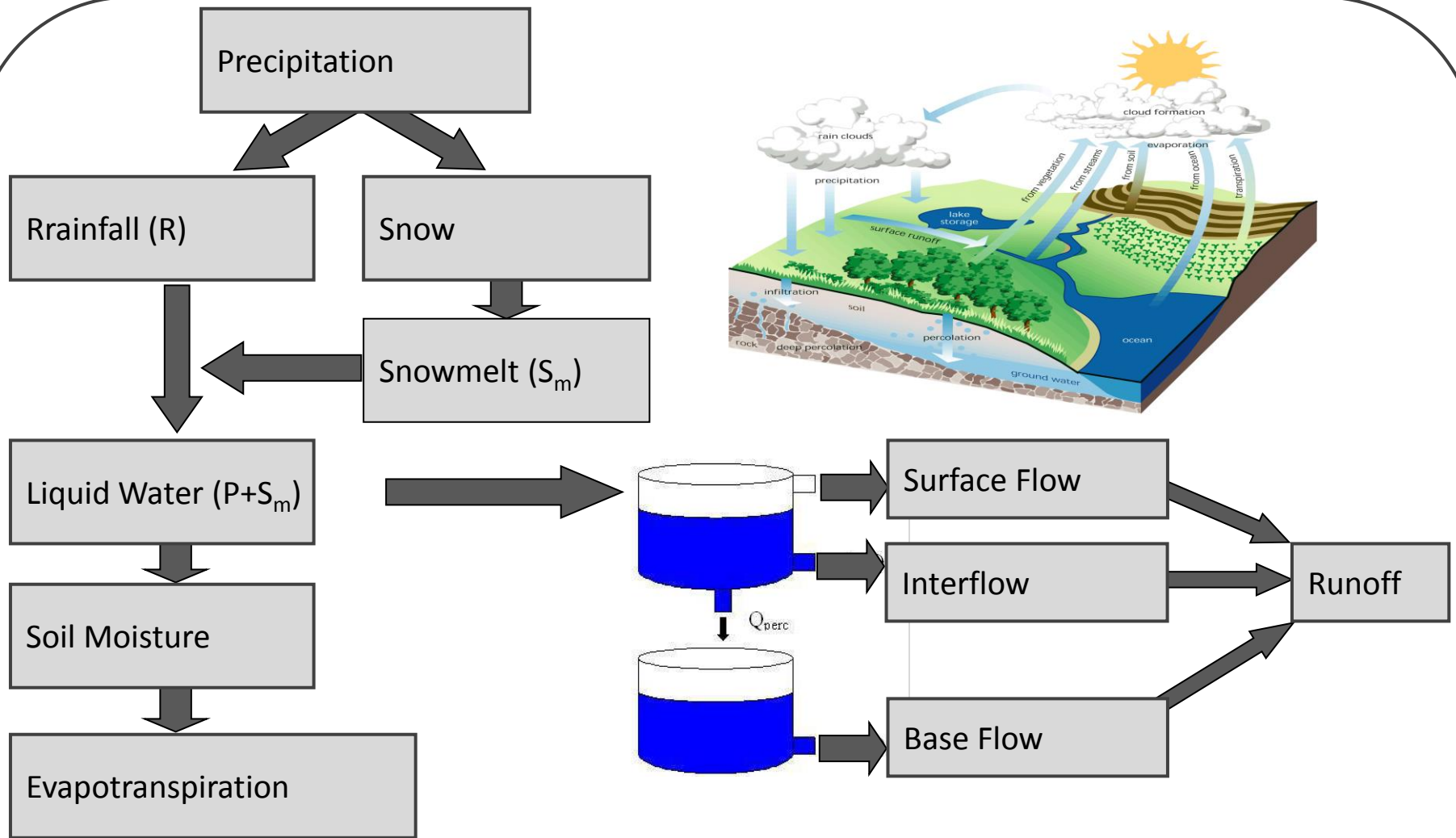
Analysis II

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

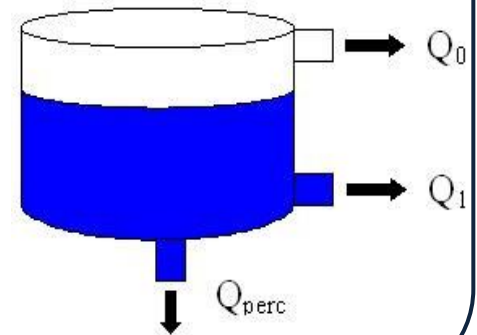
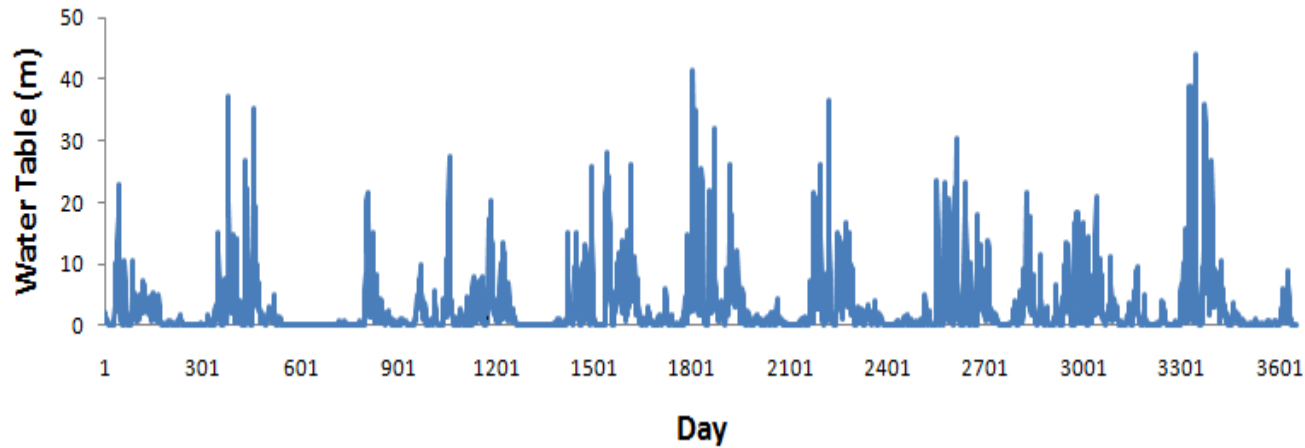


Model Structure (Review)

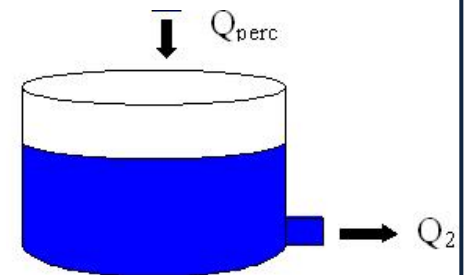
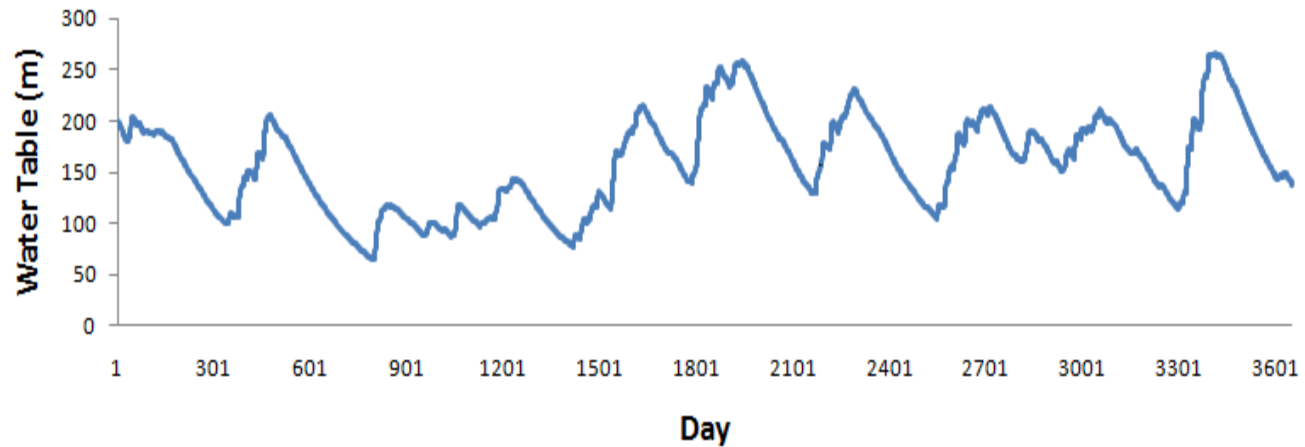


Reservoir Concept

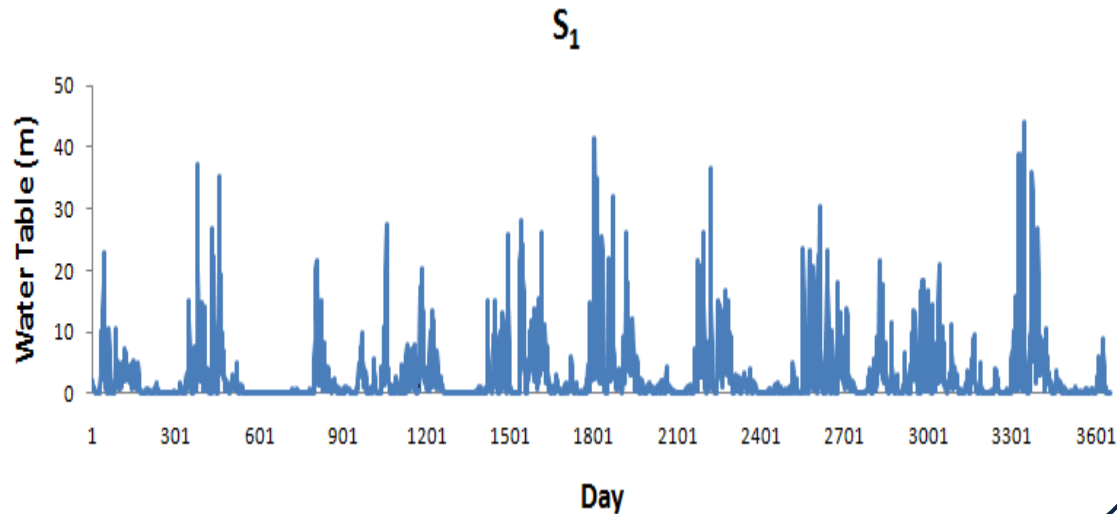
S_1



S_2



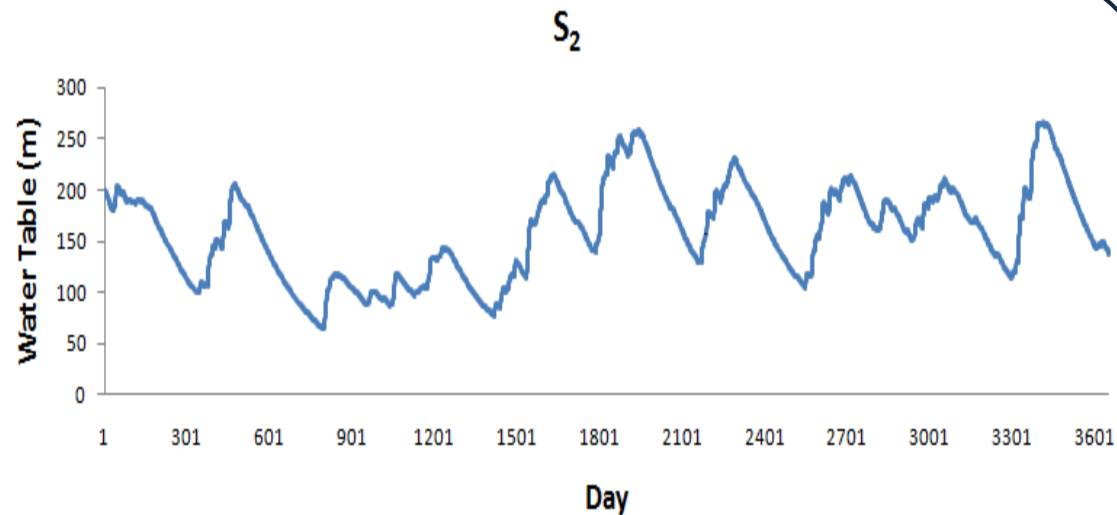
Reservoir Concept



$$Q_0 = K_0 \cdot (S_1 - L) \cdot A$$

$$Q_1 = K_1 \cdot S_1 \cdot A$$

$$Q_2 = K_2 \cdot S_2 \cdot A$$

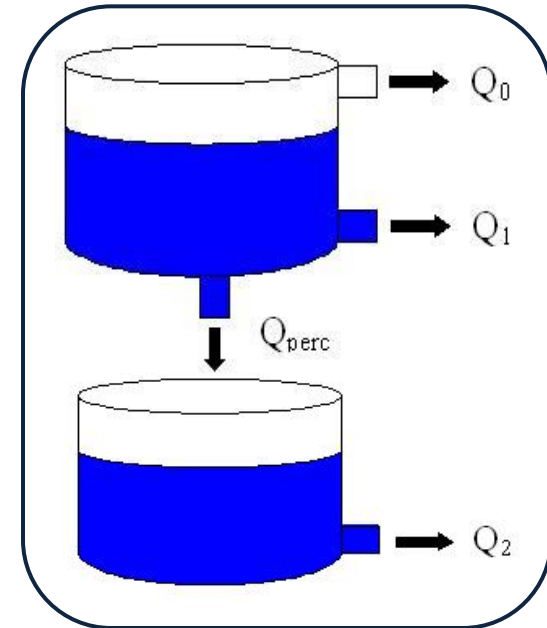


$$K_0 > K_1 > K_2$$

Runoff Response

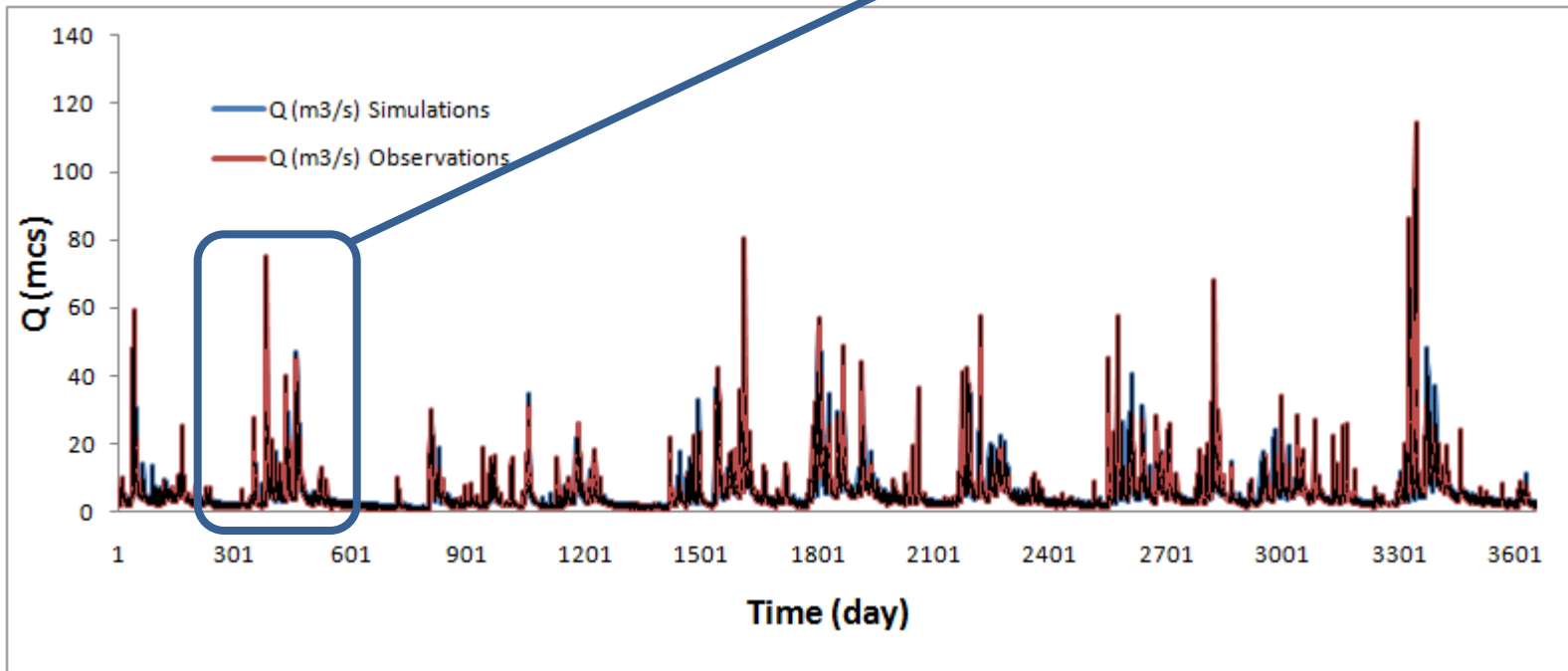
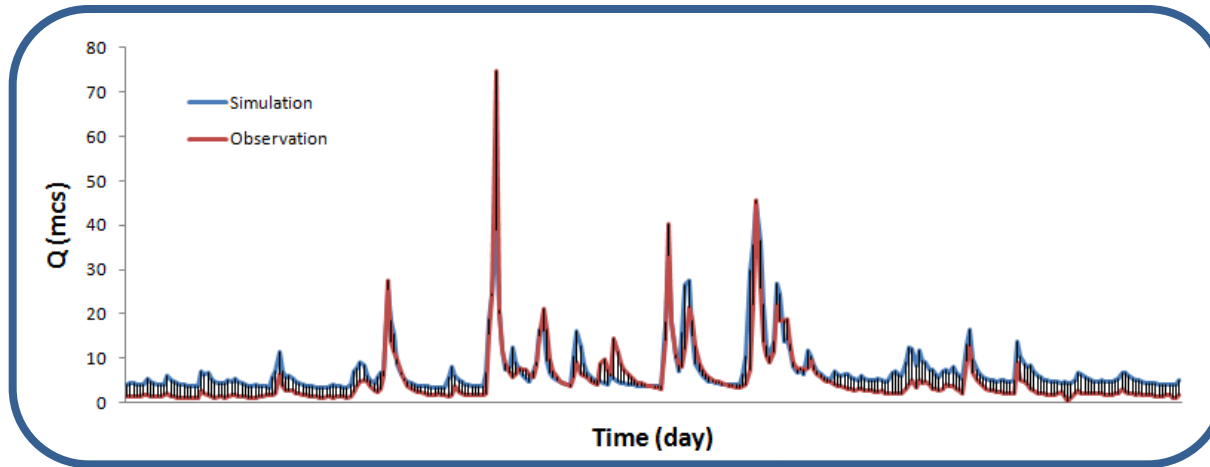
$$Q = Q_0 + Q_1 + Q_2$$

$$= \underbrace{\text{MAX}(0, K_0 - S_1) * S_1}_{K_0 (S_1 - L)} + \underbrace{K_1 * S_1}_{K_1 (S_1)} + \underbrace{L * S_1}_{K_2 (S_2)}$$



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

Ideal RMSE= 0

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

Q_s =simulated discharge

Q_o =observed discharge

Bias

Ideal Bias= 1

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

Q_s =simulated discharge

Q_o =observed discharge

Validation Criteria

Correlation Coefficient

Ideal $R_p = 1$

$R_p = -1$ Negatively correlated

$R_p = 0$ Not correlated

$R_p = 1$ Correlated

$$R_p = \frac{\sum_{i=1}^n (Q_o^i - \bar{Q}_o) \cdot \sum_{i=1}^n (Q_s^i - \bar{Q}_s)}{\sqrt{\sum_{i=1}^n (Q_o^i - \bar{Q}_o)^2} \cdot \sqrt{\sum_{i=1}^n (Q_s^i - \bar{Q}_s)^2}}$$

where:

R_p Pearson correlation coefficient [-]

\bar{Q}_s mean simulated discharge [$L^3 T^{-1}$]

Nash-Sutcliff Coefficient

Ideal $R_{NS} = 1$

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

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

where:

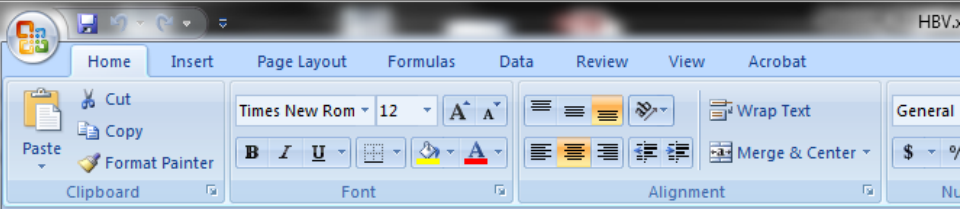
R_{NS} Nash-Sutcliffe coefficient [-]

Q_s simulated discharge [$L^3 T^{-1}$]

Q_o observed discharge [$L^3 T^{-1}$]

\bar{Q}_o mean observed discharge [$L^3 T^{-1}$]

n number of time steps



	A	B	C	D	E	F
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8	Catchment Area (Km ²)	410	K ₀ (Reservoir Par.)	0.13
9	T _i (Threshold Temp.)	0	L ₁ (Threshold W.L.)	6.00
10	DD	3	K ₁ (Reservoir Par.)	0.13
11	FC (Field Capacity)	180.0	K ₂ (Reservoir Par.)	0.00
12	BETA	3.0	K _{perc}	0.22
13	C (Model param.)	0.03	PWP	105.00

	Monthly T _{ave} .	PE _m	Daily PE _m
16	-1.4	5	0.161
17	-0.3	5	0.179
18	2.6	20	0.645
19	6.3	50	1.667
20	10.9	95	3.065
21	14.2	115	3.833
22	16.4	125	4.032
23	15.6	100	3.226
24	12.7	70	2.333
25	8.3	30	0.968
26	2.9	10	0.333
27	-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

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

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

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

Error (%) of total runoff

Date	Month ID	Temp. (C)	Preci. (mm)	Snow (mm)	Liquid Water S
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

Nash-Sutcliff Coefficient

$$R_{NS} = 1 - \frac{\sum_{t=1}^n (Q_s^t - Q_o^t)^2}{\sum_{t=1}^n (Q_o^t - \bar{Q}_o)^2} \rightarrow = (O32 - N32)^2$$

where:

R_{NS} Nash-Sutcliffe coefficient [-]

Q_s simulated discharge [L^3T^{-1}]

Q_o observed discharge [L^3T^{-1}]

\bar{Q}_o mean observed discharge [L^3T^{-1}]

n number of time steps

29	Month	Temp.	Preci.	Snow	Liquid Water	Soil Moisture	DQ (mm/day)	Potential	E _a	S ₁	S ₂	Total Q (Q _i)	Q (m ³ /s)	Q (m ³ /s)	(Q-QT) ²	(Q-Qm) ²
30	ID	(C)	(mm)	(mm)			OR P _{eff}	E. (PE _a)	(mm/day)			(mm/day)	Simulations	Observations		
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

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

where:

R_{NS} Nash-Sutcliffe coefficient [-]

Q_s simulated discharge [L^3T^{-1}]

Q_o observed discharge [L^3T^{-1}]

\bar{Q}_o mean observed discharge [L^3T^{-1}]

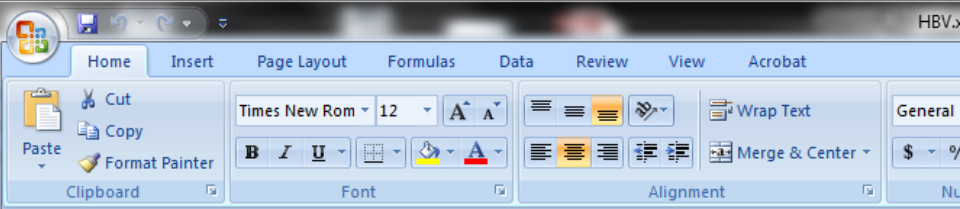
n number of time steps

Diagram illustrating the calculation of the Nash-Sutcliffe Coefficient:

The numerator is calculated as $\sum_{t=1}^n (Q_s^t - Q_o^t)^2$, which is equivalent to $=(O32-N32)^2$.

The denominator is calculated as $\sum_{t=1}^n (Q_o^t - \bar{Q}_o)^2$, which is equivalent to $=(O32-\$F\$23)^2$.

29	Month	Temp.	Preci.	Snow	Liquid Water	Soil Moisture	DQ (mm/day)	Potential	E _a	S ₁	S ₂	Total Q (Q _i)	Q (m ³ /s)	Q (m ³ /s)	(Q-QT) ²	(Q-Qm) ²
30	ID	(C)	(mm)	(mm)			OR P _{eff}	E. (PE _a)	(mm/day)			(mm/day)	Simulations	Observations		
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



	A	B	C	D	E	F
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7						
8	Catchment Area (Km ²)	410		K ₀ (Reservior Par.)	0.13	
9	T _i (Threshold Temp.)	0		L ₁ (Threshold W.L.)	6.00	
10	DD	3		K ₁ (Reservior Par.)	0.13	
11	FC (Field Capacity)	180.0		K ₂ (Reservior Par.)	0.00	
12	BETA	3.0		K _{perc}	0.22	
13	C (Model param.)	0.03		PWP	105.00	

	Monthly T _{ave.}	PE _m	Daily PE _m
15	-1.4	5	0.161
16	-0.3	5	0.179
17	2.6	20	0.645
18	6.3	50	1.667
19	10.9	95	3.065
20	14.2	115	3.833
21	16.4	125	4.032
22	15.6	100	3.226
23	12.7	70	2.333
24	8.3	30	0.968
25	2.9	10	0.333
26	-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
29						
30						
31					25	
32	1/1/1991	1	-1.5	0.4	25.4	0
33	1/2/1991	1	-0.8	10.5	35.9	0
34	1/3/1991	1	-2.8	0.9	36.8	0
35	1/4/1991	1	-3.7	4.4	41.2	0
36	1/5/1991	1	-6.1	0.6	41.8	0
37	1/6/1991	1	-3	0	41.8	0
38	1/7/1991	1	-0.7	4.4	46.2	0
39	1/8/1991	1	1.8	3.1	40.8	8.5
40	1/9/1991	1	0.6	1.7	39	3.5
41	1/10/1991	1	1.8	3.6	33.6	9

Model Parameters

Conceptual

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

Conceptual & Measurable

- FC
- DD
- PWP
- T_t

Initial Conditions

- 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

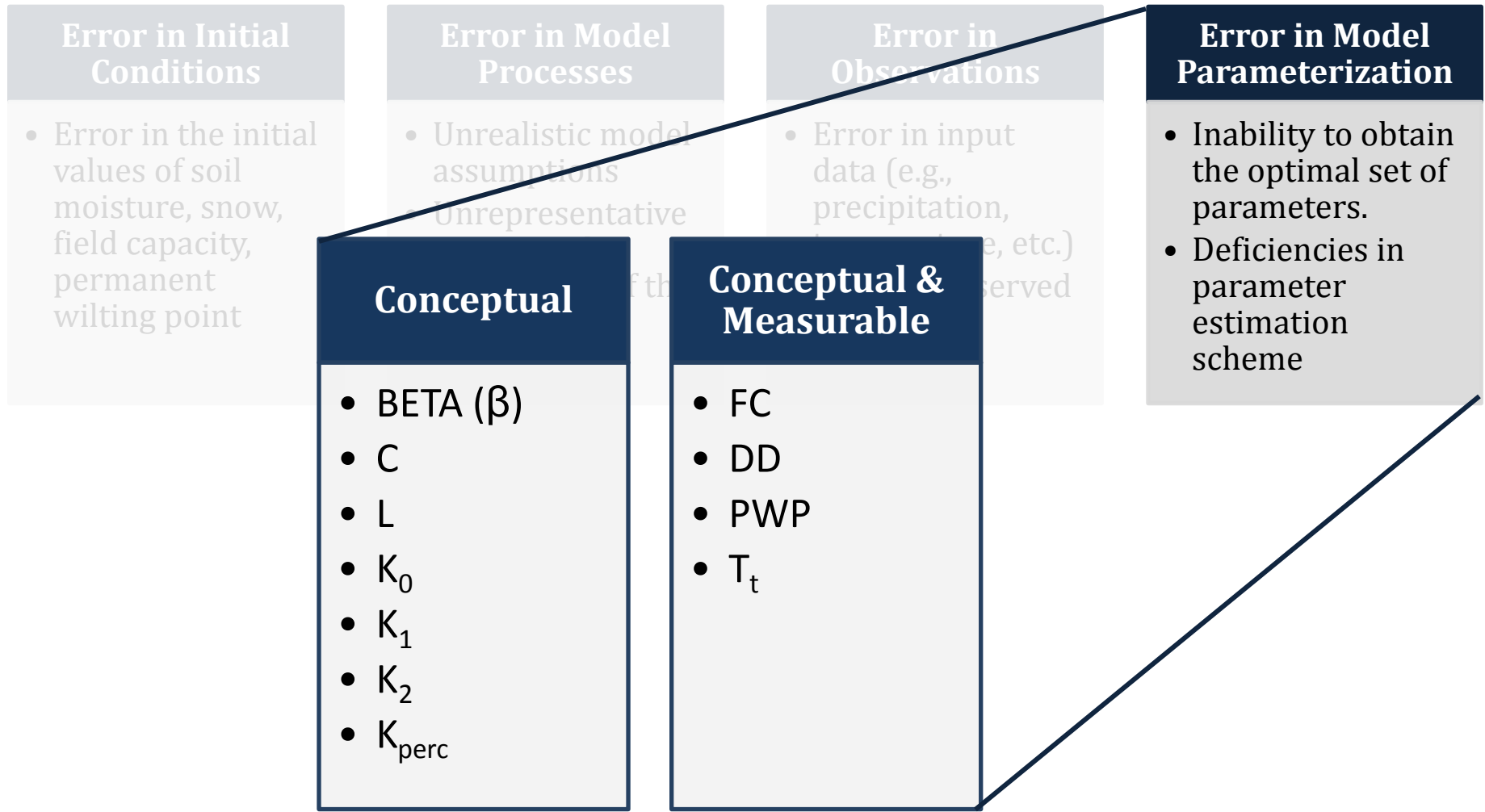
Error in Observations

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

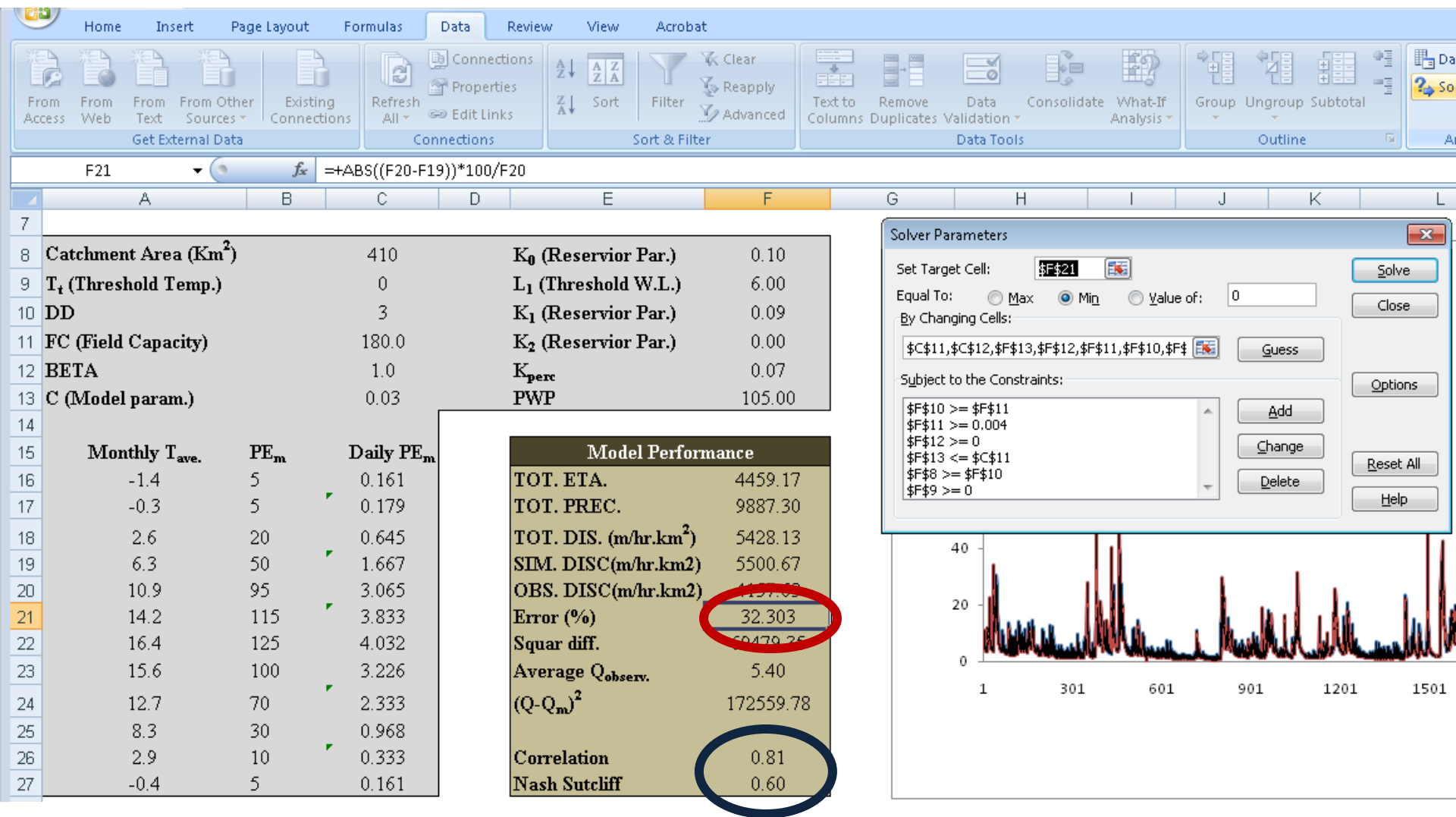
Error in Model Parameterization

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

Error Sources



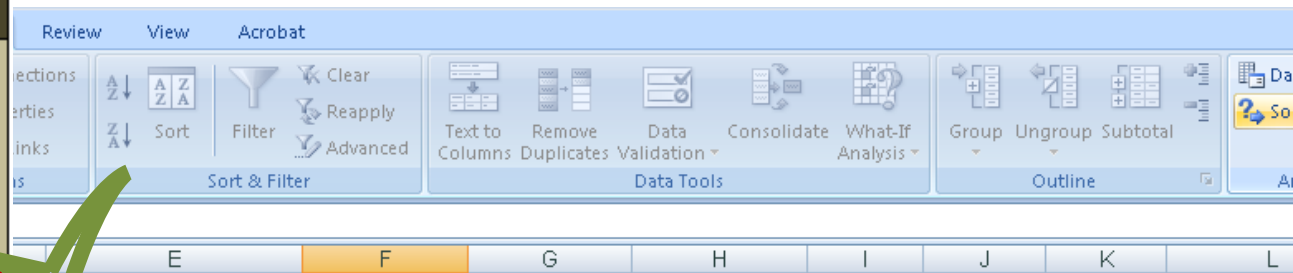
Parameter Estimation



Parameter Estimation

After Calibration

Model Performance	
TOT. ETA.	5646.97
TOT. PREC.	9887.30
TOT. DIS. (m/hr.km ²)	4240.33
SIM. DISC(m/hr.km2)	4301.04
OBS. DISC(m/hr.km2)	4157.63
Error (%)	3.449
Squar diff.	60761.32
Average Q _{observ.}	5.40
(Q-Q _m) ²	172559.78
Correlation	0.81
Nash Sutcliff	0.65



K ₀ (Reservoir Par.)	0.10
L ₁ (Threshold W.L.)	6.00
K ₁ (Reservoir Par.)	0.09
K ₂ (Reservoir Par.)	0.00
K ₃	0.07
IMP	105.00

Solver Parameters

Set Target Cell:

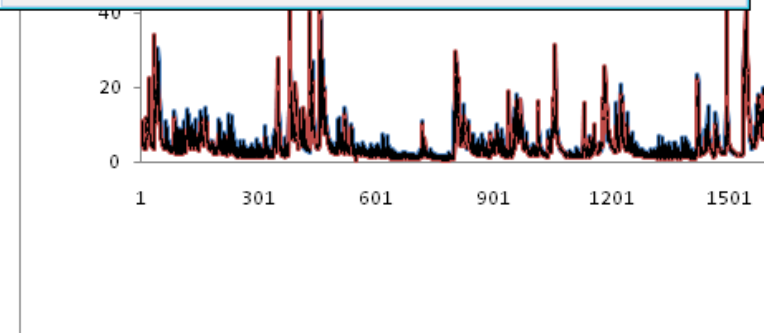
Equal To: ☐ Max ☒ Min ☐ Value of:

By Changing Cells:

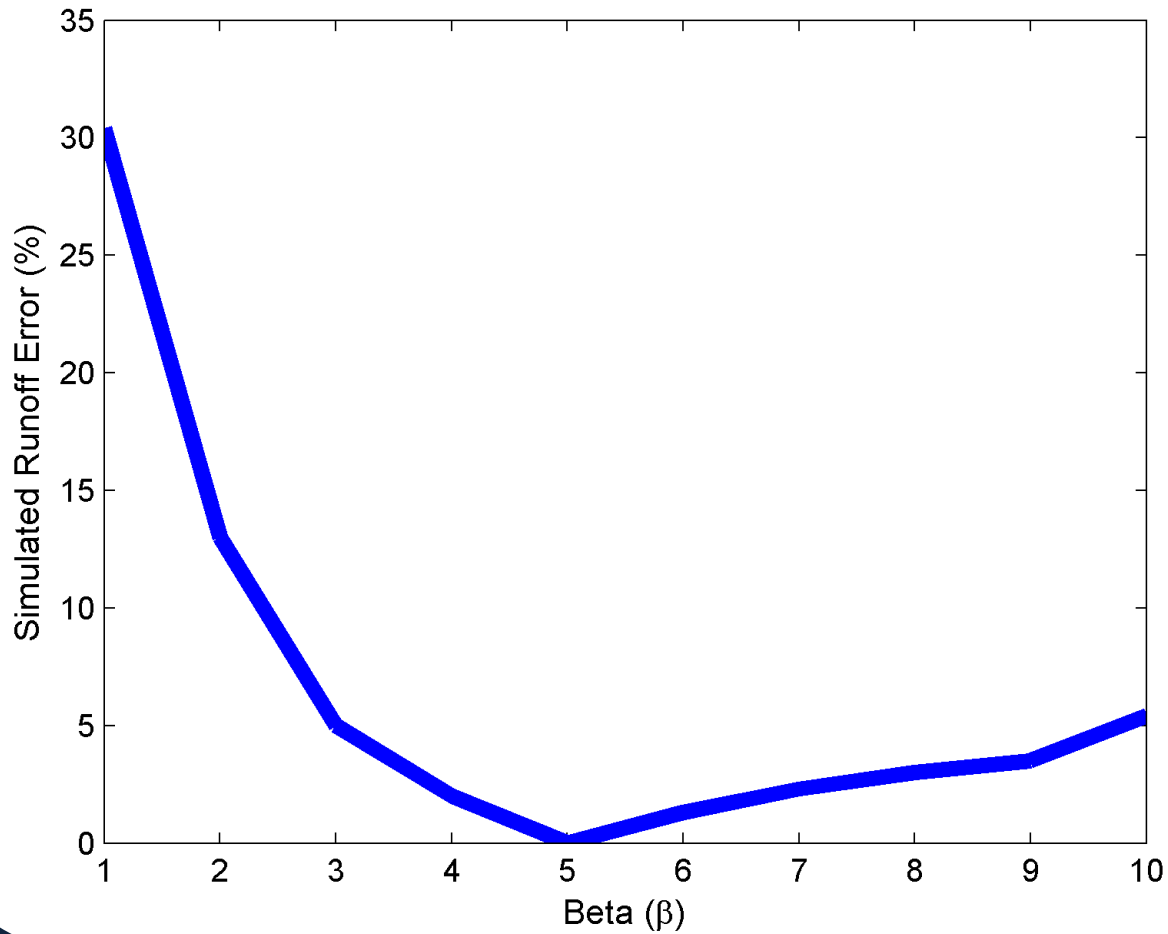
Subject to the Constraints:

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

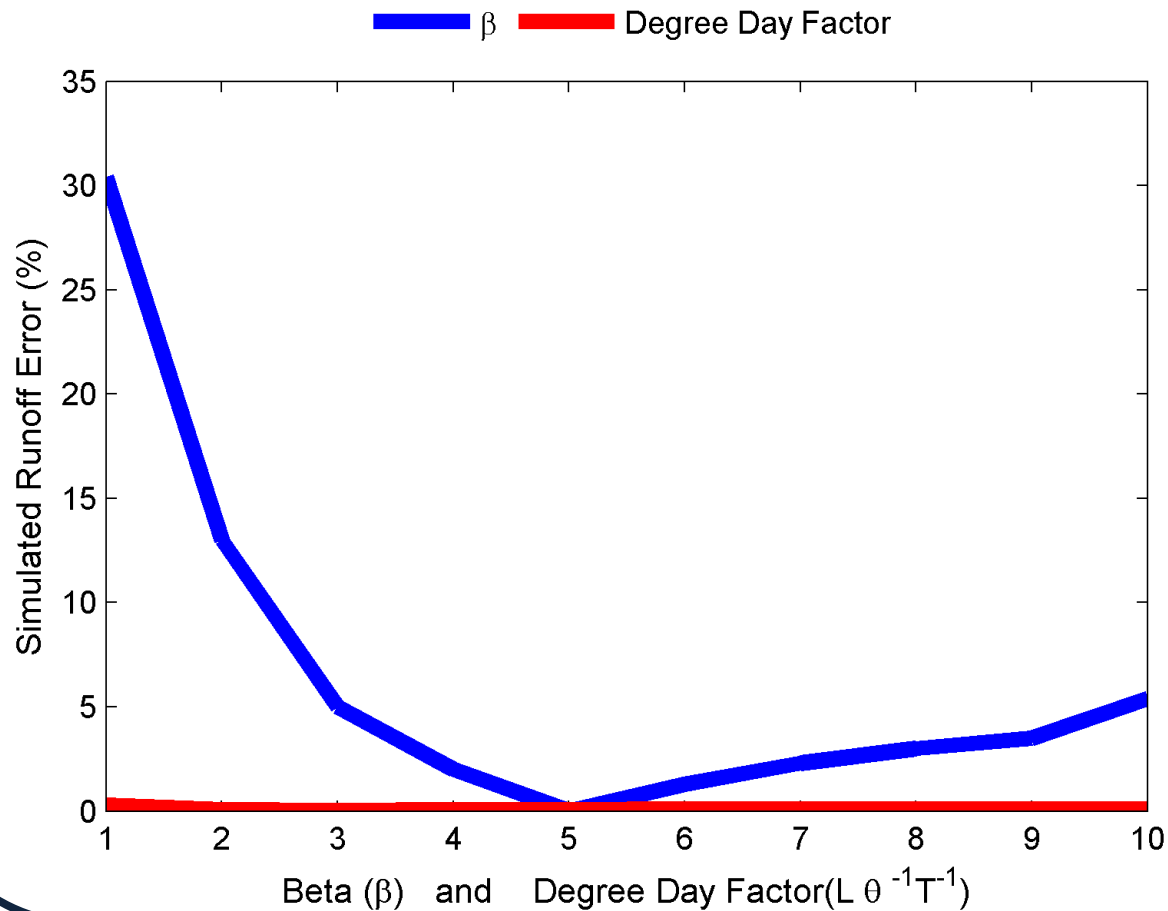
Model Performance	
TOT. ETA.	4459.17
TOT. PREC.	9887.30
TOT. DIS. (m/hr.km ²)	5428.13
SIM. DISC(m/hr.km2)	5500.67
OBS. DISC(m/hr.km2)	4157.63
Error (%)	32.303
Squar diff.	60479.26
Average Q _{observ.}	5.40
(Q-Q _m) ²	172559.78
Correlation	0.81
Nash Sutcliff	0.60



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

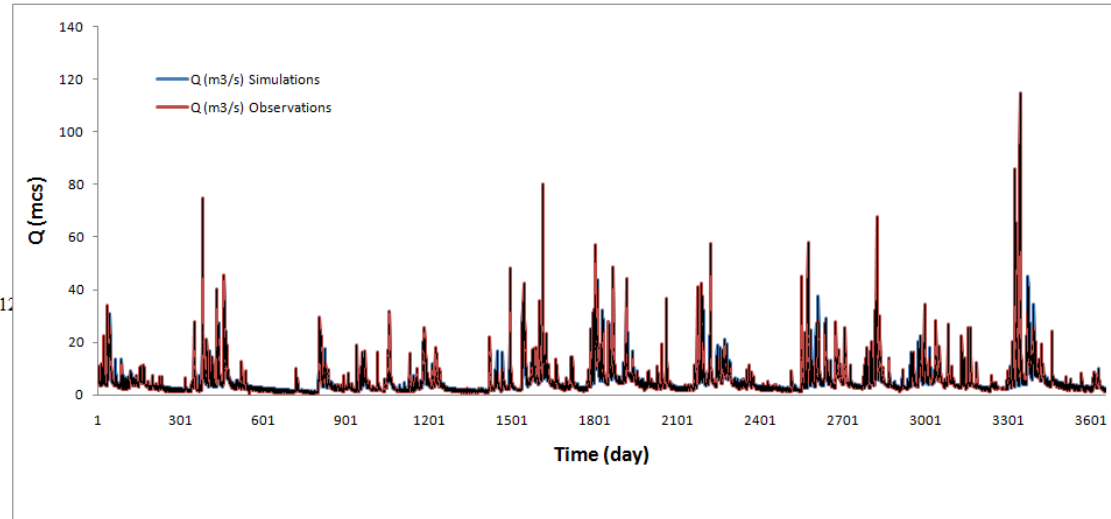
- Snow
- Soil Moisture
- S_1
- S_2

Initial Condition Error

Catchment Area (Km ²)	410	K ₀ (Reservoir Par.)	0.13
T _i (Threshold Temp.)	0	L ₁ (Threshold W.L.)	6.00
DD	3	K ₁ (Reservoir Par.)	0.13
FC (Field Capacity)	180.0	K ₂ (Reservoir Par.)	0.00
BETA	5.0	K _{perc}	0.22
C (Model param.)	0.03	PWP	105.00

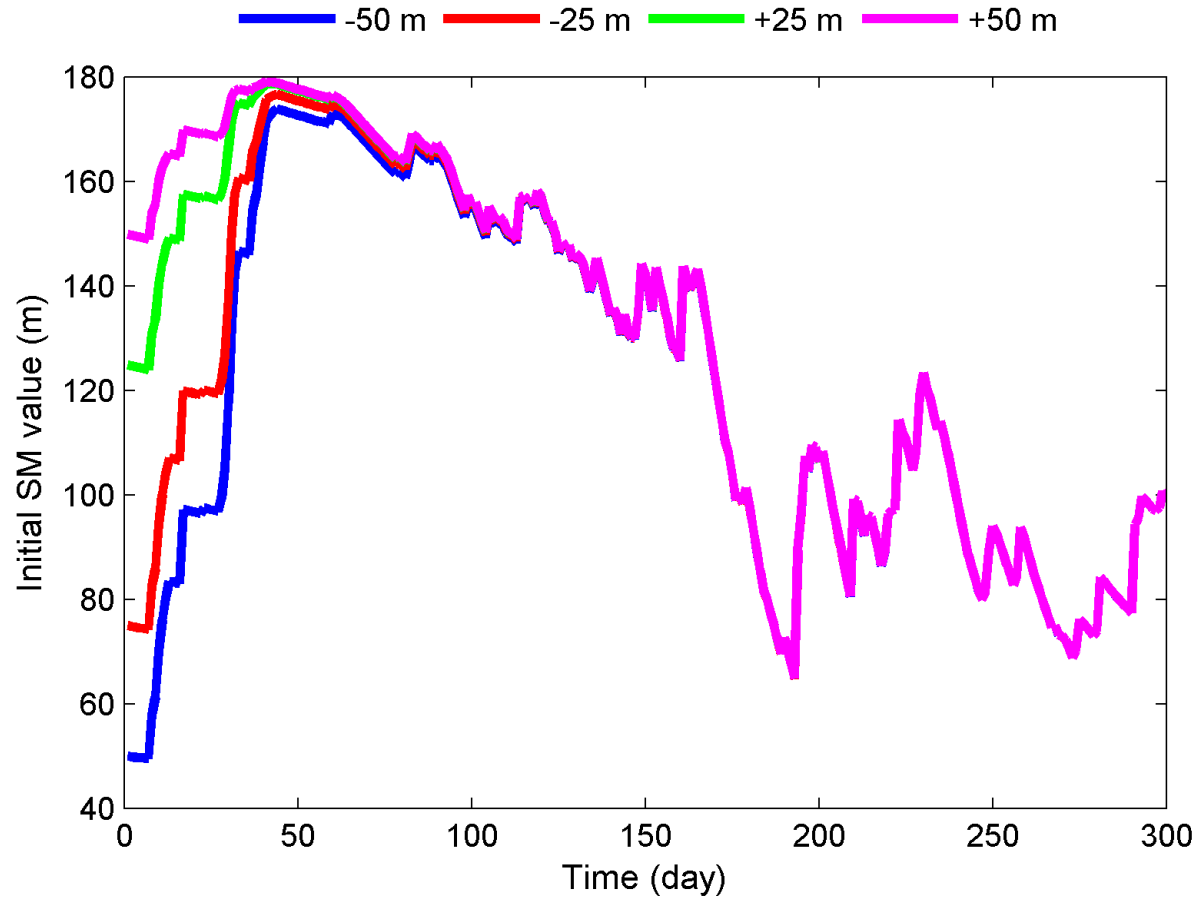
Monthly T _{ave.}	PE _m	Daily PE _m	Model Performance	
-1.4	5	0.161	TOT. ETA.	5736.08
-0.3	5	0.179	TOT. PREC.	9887.30
2.6	20	0.645	TOT. DIS. (m/hr.km ²)	4151.22
6.3	50	1.667	SIM. DISC(m/hr.km2)	4157.68
10.9	95	3.065	OBS. DISC(m/hr.km2)	4157.63
14.2	115	3.833	Error (%)	0.001
16.4	125	4.032	Squar diff.	52400.87
15.6	100	3.226	Average Q _{observ.}	5.40
12.7	70	2.333	(Q-Q _m) ²	172559.78
8.3	30	0.968	Correlation	0.84
2.9	10	0.333	Nash Sutcliffe	0.70
-0.4	5	0.161		

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

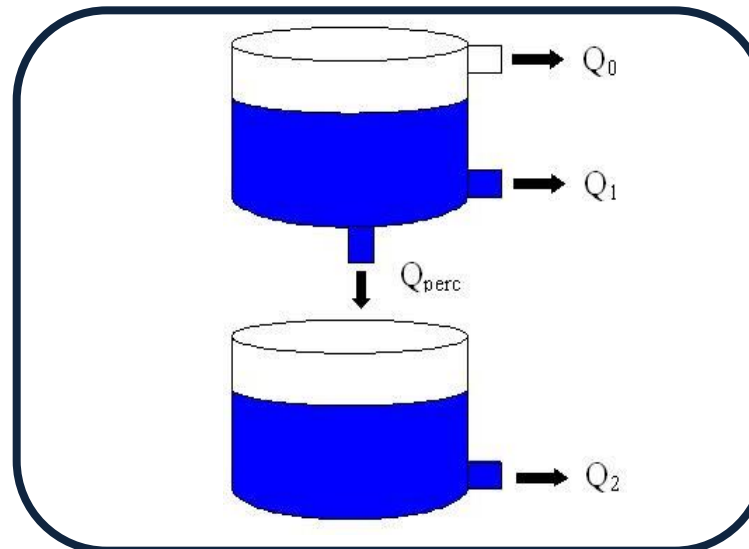
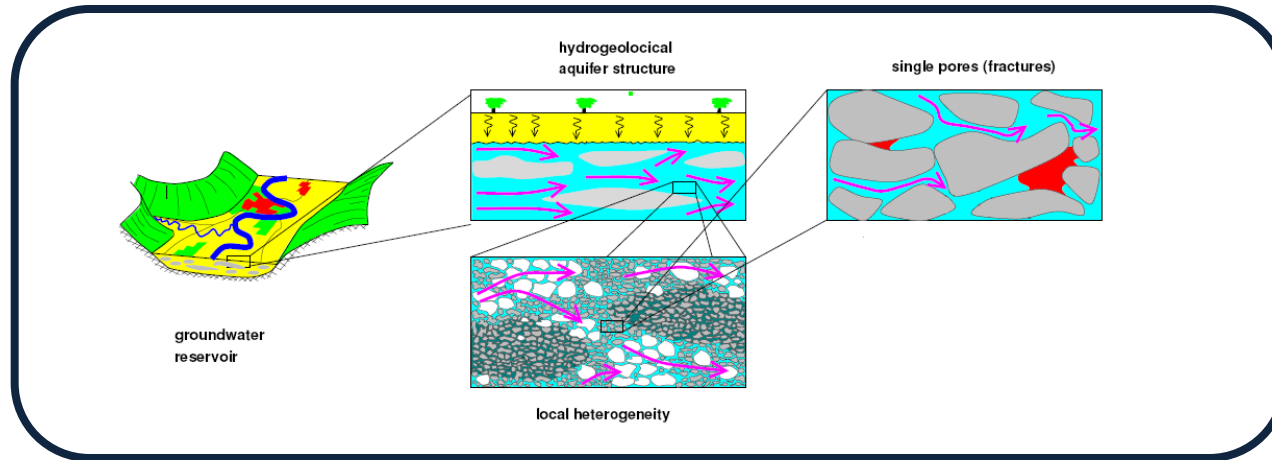
Error in Observations

- 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 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 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

Water Science and Technology Library

Amir AghaKouchak · David Easterling
Kuolin Hsu · Siegfried Schubert
Soroosh Sorooshian *Editors*

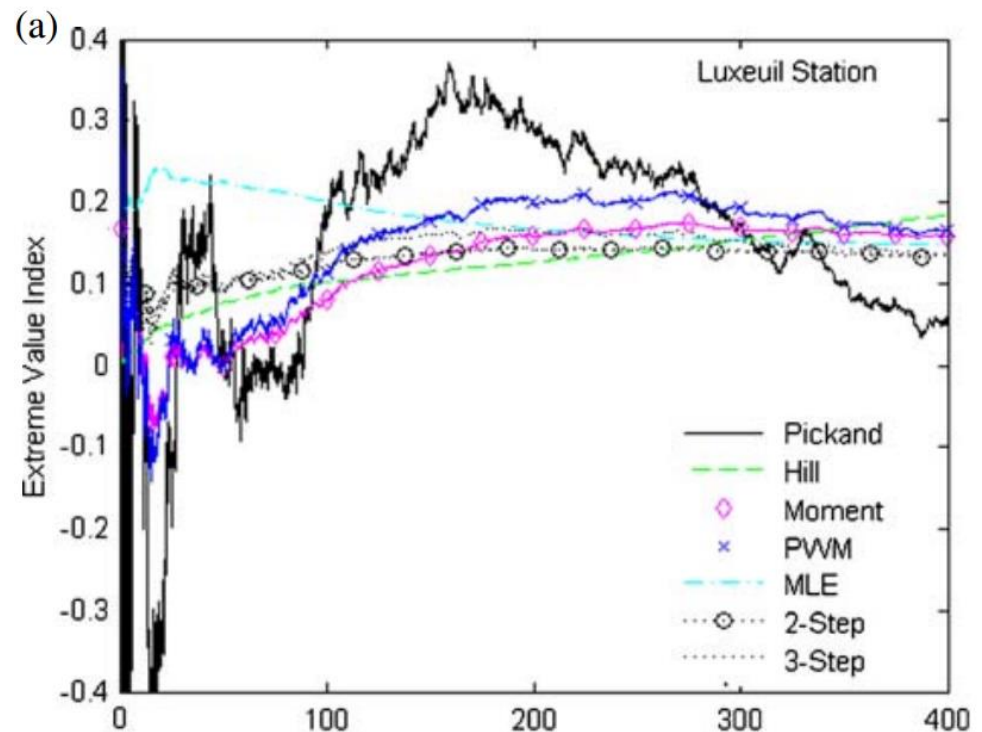
Extremes in a Changing Climate

Detection, Analysis and Uncertainty

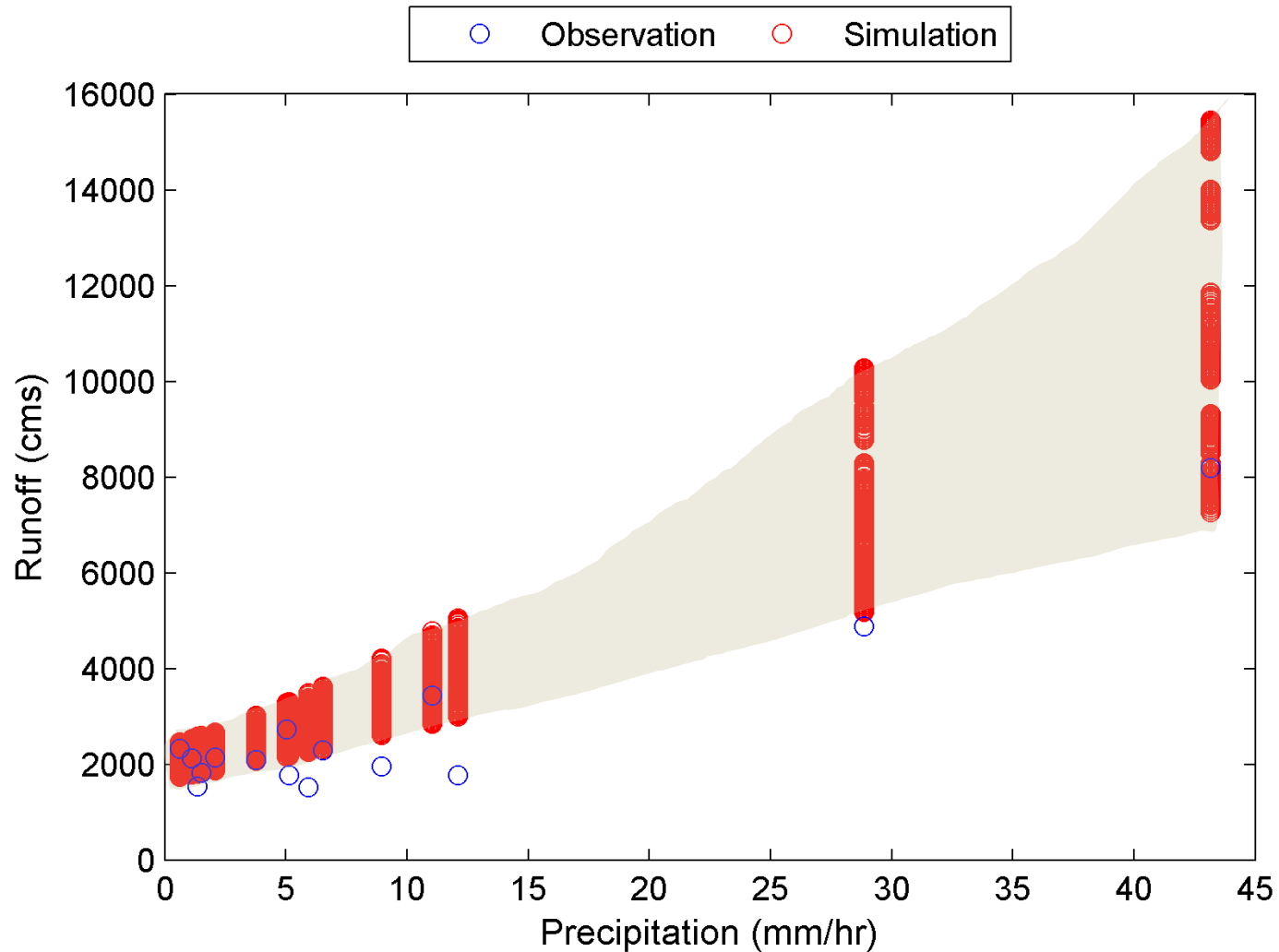
 Springer

1- Run the model with different GCM outputs

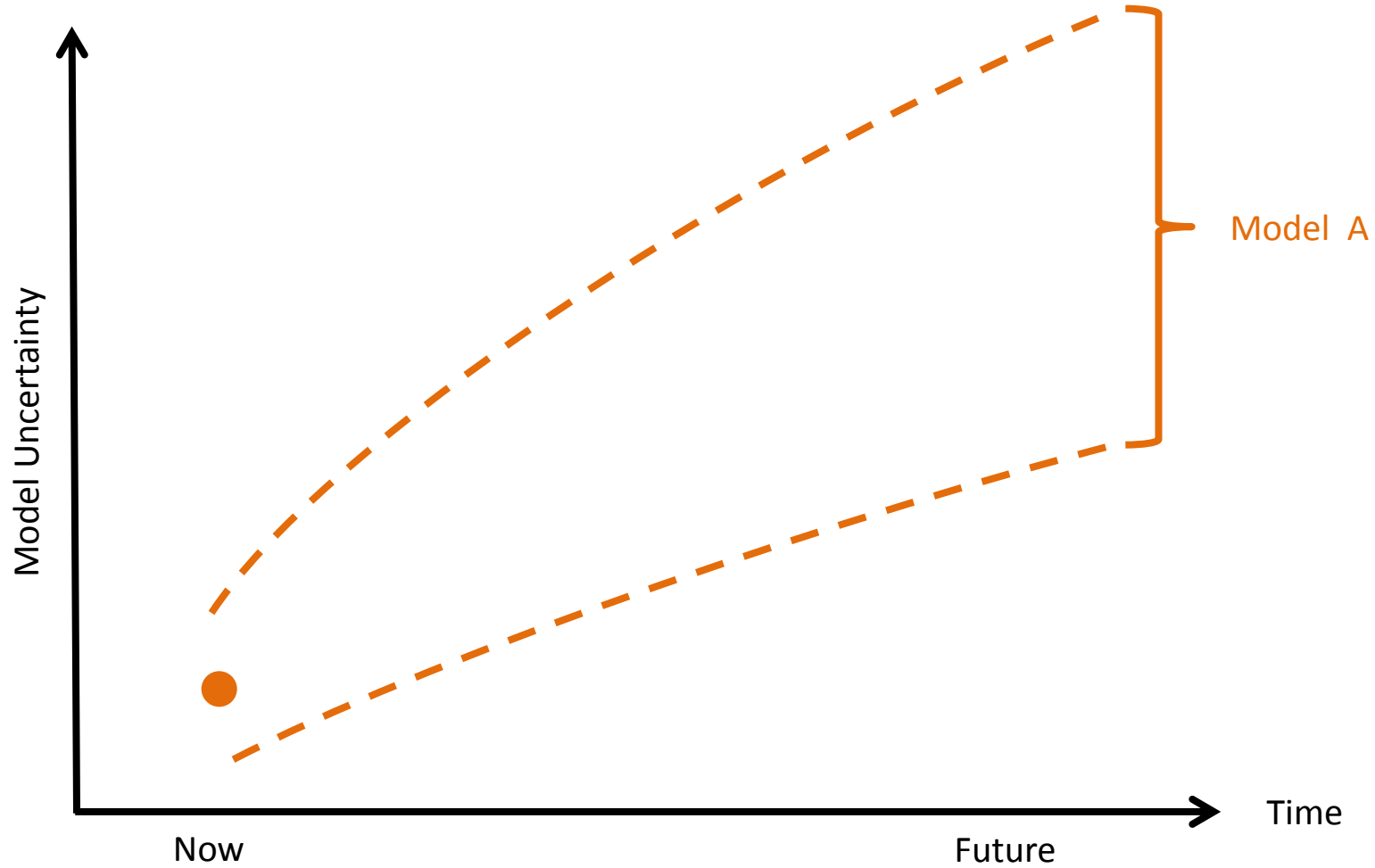
2- Analyze data using the Extreme Value Theory



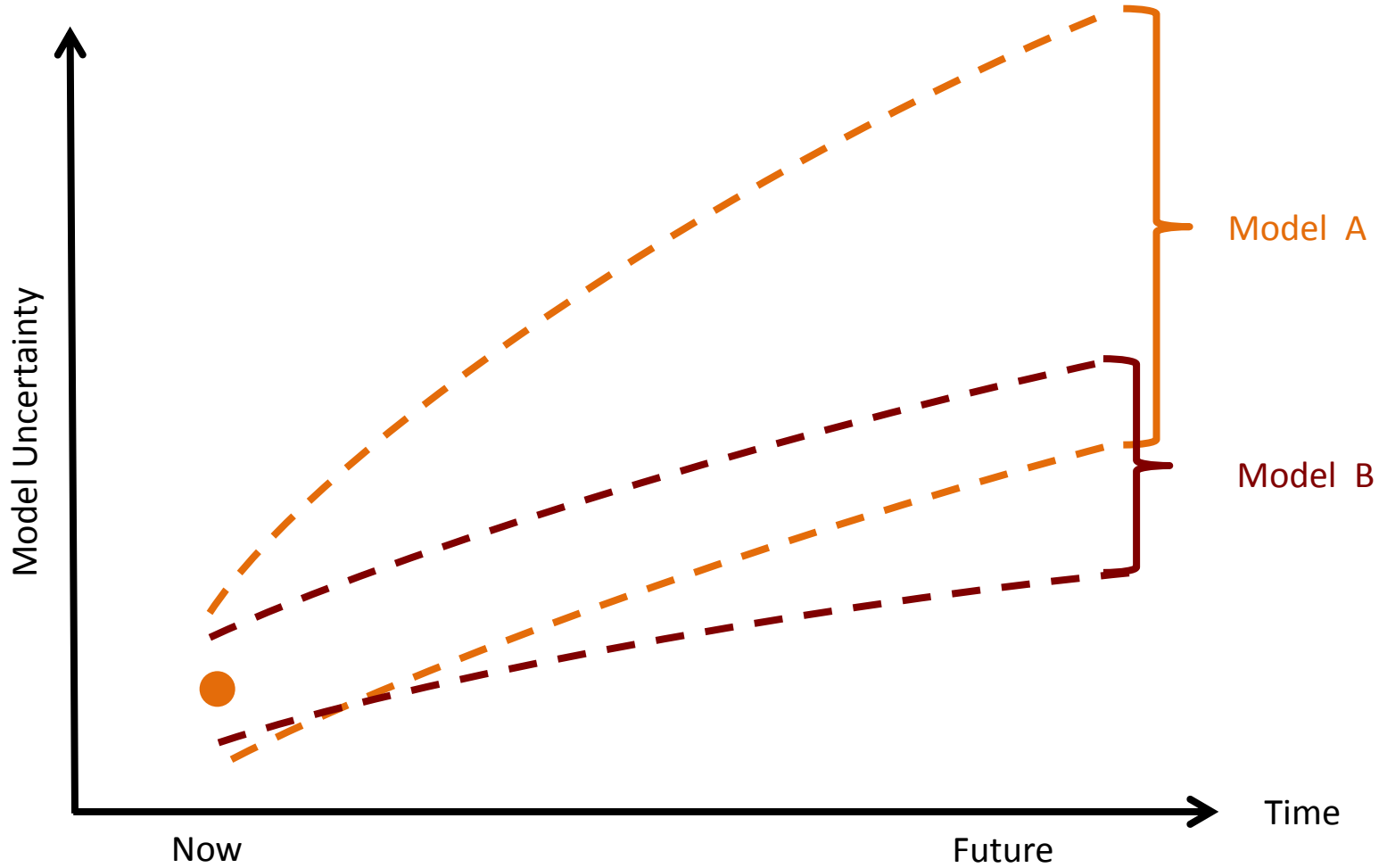
Model Uncertainty – Ensemble Simulation



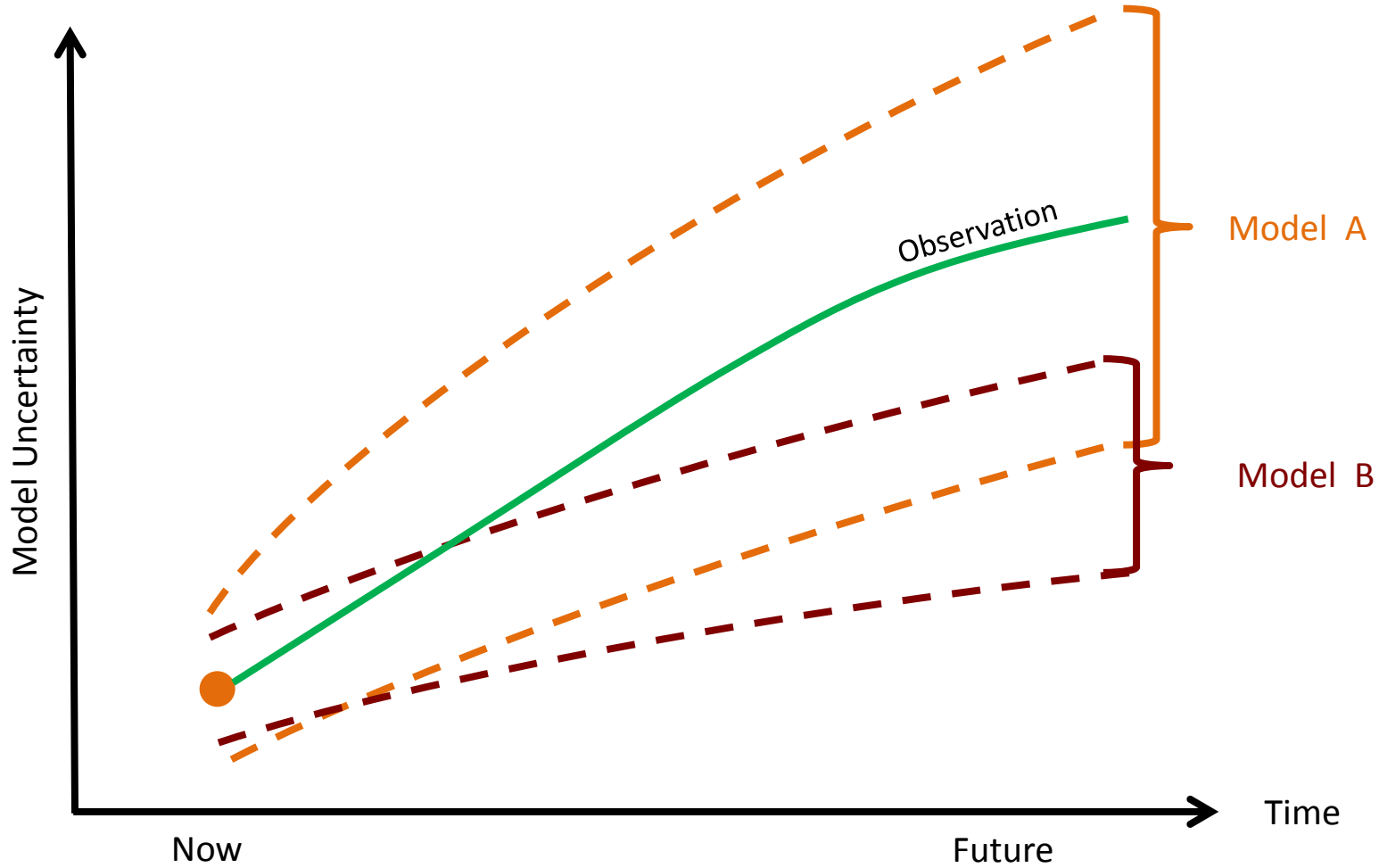
Model Uncertainty



Model Uncertainty



Model Uncertainty



HBV-EDU

HBV-EDU Ver. 2

Contact
 AghaKouchak & Emad Habib
 For questions and permissions contact:
 Dr. Amir AghaKouchak (amir.a@uci.edu)
 OR Dr. Emad Habib (habib@louisiana.edu)

Model Parameters

Parameters	Bounds	Optimal
DO	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	
PVP	90 180	

Watershed Area & Snow Melt Thr.

Area	410
T ₁	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
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Optimization Criteria
 Qrmse (Root Mean Square Error)

Model Performance

Correlation

Nash Sutcliffe

Initial Values

Snow	0.0
Soil Moisture	100.0
S_1	2.0
S_2	200.0

Select Parameter to Plot
 Select Plot

MM	DO	YYYY	Temp.	Precip.	Snow	Liquid Water	Soil Moisture	Dq	Pot. Evap.	Evap.	S_1	S_2	Q obs	Q sim
List	List	Listbo	Temper	Precip	Snow	Liquid W	Soil Moistu	Dq	Pot. Evap.	Evap.	S1	S2	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 permissions contact:
Dr. Amir AghaKouchak (amir.a@uci.edu)
OR Dr. Emad Habib (habib@louisiana.edu)

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
T₁: 0

Input Data Based on Monthly Climatological Data

Monthly Temp.	Monthly PE	Daily PE
Temp.	Monthly PE	Daily PE

Cite this program as:
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Optimization Criteria
Grmse (Root Mean Square Error)

Select Parameter to Plot
Select Plot

Model Performance

Correlation

Nash Sutcliff

Initial Values

Snow: 0.0
Soil Moisture: 100.0
S₁: 2.0
S₂: 200.0

MM DD YYYY Temp. Precip. Snow Liquid Water Soil Moisture Dq Pot. Evap. Evap. S₁ S₂ Q obs Q sim

Source Code:
<http://amir.eng.uci.edu/software.html>

Executable Version:
<http://amir.eng.uci.edu/education.html>

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 Ver. 2
AghaKouchak & Emad Habib
For questions and permissions contact:
Dr. Amir AghaKouchak (amir.a@uci.edu)

Model Parameters

Parameters	Bounds	Optimal
DD	4 7	<input type="checkbox"/>
FC	100 200	<input type="checkbox"/>
Beta	1 4	<input type="checkbox"/>
C	0.03 0.07	<input type="checkbox"/>
K ₀	0.2 0.4	<input type="checkbox"/>
L	2.0 5	<input type="checkbox"/>
K ₁	0.01 0.2	<input type="checkbox"/>
K ₂	0.01 0.1	<input type="checkbox"/>
K _p	0.01 0.1	<input type="checkbox"/>
PWP	90 180	<input type="checkbox"/>

Watershed Area & Snow Melt Thr.

Area	410
T ₁	0

Input Data Based on Monthly Climatological Data

Monthly Temp.	Monthly PE	Daily PE
Temp.	Monthly PE	Daily PE

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Optimization Criteria
Gmse (Root Mean Square Error)

Select Parameter to Plot
Select Plot

Model Performance

Correlation	
Nash Sutcliffe	

MM	DD	YYYY	Temp.	Precip.	Snow	Liquid Water	Soil Moisture	Dq	Pot. Evap.	Evap.	S ₁	S ₂	Q obs	Q sim
List	List	Listbo	Temper	Precip	Snow	Liquid W	Soil Moistu	Dq	Pot. Evap.	Evap.	S1	S2	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 Ver. 2
 AghaKouchak & Emad Habib
 For questions and permissions contact:
 Dr. Amir AghaKouchak (amir.a@ucd.edu)

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

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

Run

of simulations: 50

Simulate Q

HBV-EDU

HBV_EDU_V2

Help

Contact:
HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permissions contact:
Dr. Amir AghaKouchak (amir.gha@utdallas.edu)

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
S₁: 2.0
S₂: 200.0

Input Data Based on Monthly Climatological Data

Monthly Temp.	Monthly PE	Daily PE
Temp.	Monthly PE	Daily PE

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Optimization Criteria
Gmse (Root Mean Square Error)

Select Parameter to Plot
Select Plot

Model Performance
Correlation
Nash Sutcliffe

MM	DD	YYYY	Temp.	Precip.	Snow	Liquid Water	Soil Moisture	Dq	Pot. Evap.	Evap.	S ₁	S ₂	Q obs	Q sim
List	Listbo	Temp	Precip	Snow	Liquid W	Soil Moistu	Dq	Pot. Evap	Evap	S1	S2	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

Upper Bound of parameter

HBV-EDU

HBV_EDU_V2

Help

Contact
HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permissions contact:
Dr. Amir AghaKouchak (amir@uwaterloo.ca)

Watershed Area & Snow Melt Thr.
Area: 410
T_t: 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
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Optimization Criteria
Grmse (Root Mean Square Error)

Select Parameter to Plot
Select Plot

Model Performance
Correlation
Nash Sutcliffe

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
S₁: 2.0
S₂: 200.0

Lower Bound of parameter

MM	DD	YYYY	Temp.	Precip.	Snow	Liquid Water	Soil Moisture	Dq	Pot. Evap.	Evap.	S ₁	S ₂	Q obs	Q sim
Let	List	Listbo	Temper	Precip	Snow	Liquid W	Soil Moistu	Dq	Pot. Evap	Evap	S1	S2	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

http://www.aghakouchak.com/_/rsrc/ces/hm/hbv_edu/HBV_EDU_GUI.png

HBV-EDU

HBV_EDU_V2

Help

Contact:
HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permissions contact:
Dr. Amir AghaKouchak (amir.akh@uwaterloo.ca)

Watershed Area & Snow Melt Thr.
Area: 410
T_t: 0

Input Data Based on Monthly Climatological Data
Monthly Temp.: Temp.
Monthly PE: Monthly PE
Daily PE: Daily PE

Cite this program as:
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Acknowledgment
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Optimization Criteria
Grmse (Root Mean Square Error)

Select Parameter to Plot
Select Plot

Model Performance
Correlation
Nash Sutcliff

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
S₁: 2.0
S₂: 200.0

MM DD YY Temp. Precip. Snow Liquid Water Soil Moisture Dq Pot. Evap. Evap. S₁ S₂ 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

Optimal Parameter (after calibration)

HBV-EDU

HBV_EDU_V2

Help

Contact

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AghaKouchak & Emad Habib
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Dr. Amir AghaKouchak (amir.a@uci.edu)
OR Dr. Emad Habib (habib@louisiana.edu)

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

Input Data Based on Monthly Climatological Data

Monthly Temp.	Monthly PE	Daily PE
Temp.	Monthly PE	Daily PE

Cite this program as:
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Optimization Criteria
Grmse (Root Mean Square Error)

Select Parameter to Plot
Select Plot

Model Performance
Correlation
Nash Sutcliff

Initial Values

Snow: 0.0
Soil Moisture: 100.0
S_1: 2.0
S_2: 200.0

MM	DD	YYYY	Temp.	Precip.	Snow	Liquid Water	Soil Moisture	Dq	Pot. Evap.	Evap.	S_1	S_2	Q obs	Q sim
List	List	Listbo	Temper	Precip	Snow	Liquid W	Soil Moistu	Dq	Pot. Evap	Evap	S1	S2	Q(obs)	Q(sim)

Load Input Files

Load Input Temp. & Precip. Load Monthly Temp. & Evap. Load Observed Q Reset

Run

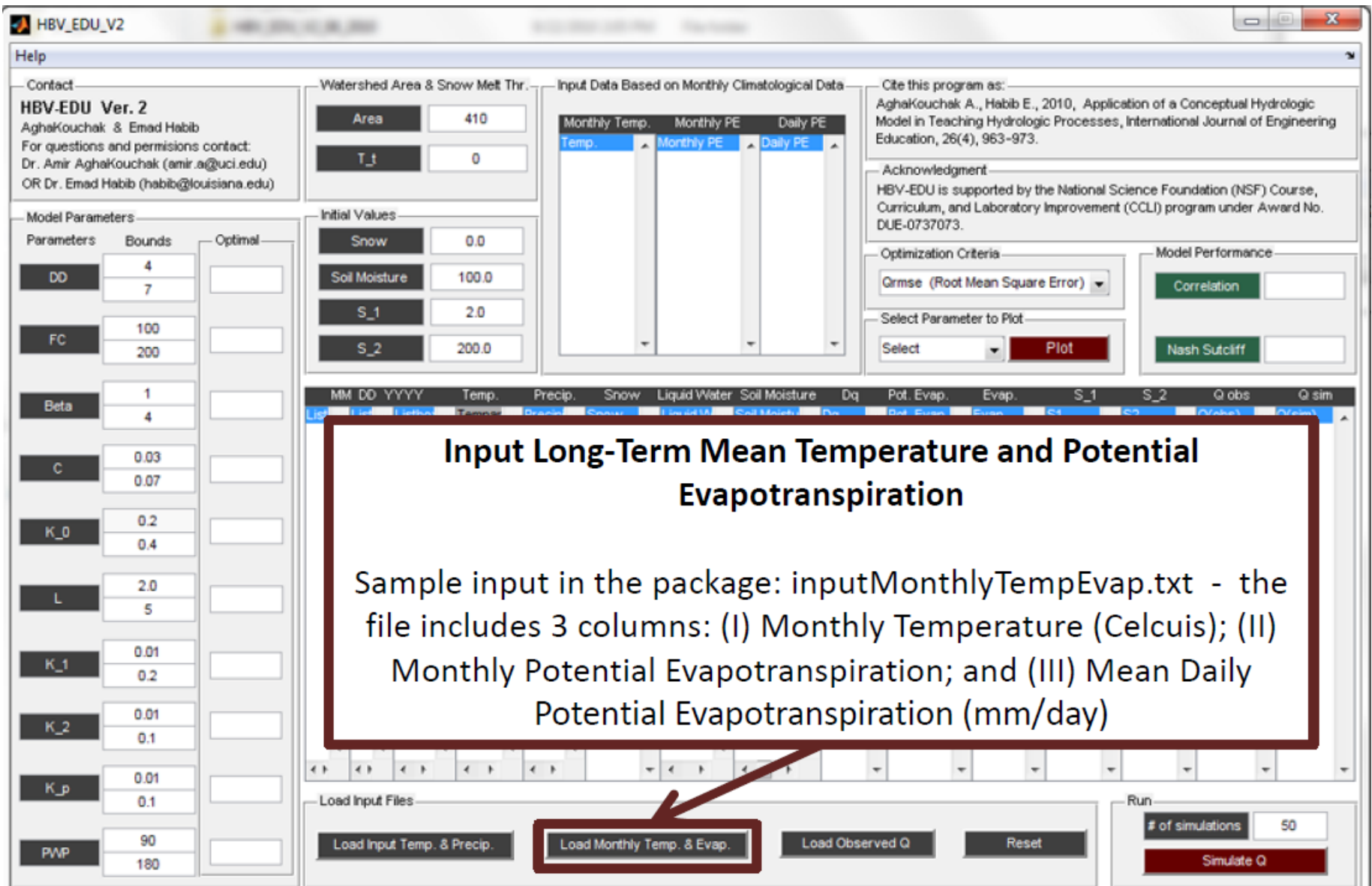
of simulations: 50
Simulate Q

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

HBV-EDU



HBV-EDU

HBV_EDU_V2

Help

Contact—
HBV-EDU Ver. 2
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For questions and permissions contact:
Dr. Amir AghaKouchak (amir.a@uci.edu)
OR Dr. Emad Habib (habib@louisiana.edu)

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 ₁	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—
Ormse (Root Mean Square Error)

Select Parameter to Plot—
Select Plot

Model Performance—
Correlation
Nash Sutcliffe

Initial Values—

Snow	0.0
Soil Moisture	100.0
S ₁	2.0
S ₂	200.0

MM DD YYYY Temp. Precip. Snow Liquid Water Soil Moisture Dq Pot. Evap. Evap. S₁ S₂ 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

The screenshot displays the HBV-EDU V2 software interface. The window title is "HBV_EDU_V2". The interface is divided into several sections:

- Contact:** HBV-EDU Ver. 2, AghaKouchak & Emad Habib. For questions and permissions 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. Temp., Monthly PE, Daily PE.
- Model Parameters:** Parameters, Bounds, Optimal. DD: 4, 7. FC: 100, 200. Beta: 1, 4. C: 0.03, 0.07. K₀: 0.2, 0.4. L: 2.0, 5. K₁: 0.01, 0.2. K₂: 0.01, 0.1. K_p: 0.01, 0.1. PWP: 90, 180.
- Initial Values:** Snow: 0.0, Soil Moisture: 100.0, S₁: 2.0, S₂: 200.0.
- Optimization Criteria:** Qrmse (Root Mean Square Error) is selected. A red box highlights this section with an arrow pointing to the "Plot" button.
- Model Performance:** Correlation, Nash Sutcliff.
- Simulation Table:** MM, DD, YYYY, Temp., Precip., Snow, Liquid Water, Soil Moisture, Dq, Pot. Evap., Evap., S₁, S₂, Q obs, Q sim. The table has columns for input data and simulation results.
- Buttons:** Load Input Temp. & Precip., Load Monthly Temp. & Evap., Load Observed Q, Reset, Simulate Q.
- Simulation Settings:** # of simulations: 50.

Optimization (Parameter Estimation) Criteria

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

- Qrms (Root mean square error)
- NSC (Nash-Sutcliffe Coefficient)
- Corr (Correlation Coefficient)

http://www.aghakouchak.com/_rsrc/128ces/hm/hbv_edu/HBV_EDU_GUI.png

HBV-EDU

HBV_EDU_V2

Help

Contact

HBV-EDU Ver. 2
AghaKouchak & Emad Habib
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OR Dr. Emad Habib (habib@louisiana.edu)

Watershed Area & Snow Melt Thr.

Area: 410
T_m: 0

Input Data Based on Monthly Climatological Data

Monthly Temp.: Temp.
Monthly PE: Monthly PE
Daily 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
Gmse (Root Mean Square Error)

Select Parameter to Plot
Select Plot

Model Performance
Correlation
Nash Sutcliff

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
S₁: 2.0
S₂: 200.0

MM DD YYYY Temp. Precip. Snow Liquid Water Soil Moisture Dq Pot. Evap. Evap. S₁ S₂ Q obs Q sim

Load Input Files

Load Input Temp. & Precip. Load Monthly Temp. & Evap. Load Observed Q Reset

of simulations: 50

Simulate Q

Number of Simulations
(Combinations of Parameters)

HBV-EDU

HBV_EDU_V2

Help

Contact

HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permissions 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.: Temp.
Monthly PE: Monthly PE
Daily 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
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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
S₁: 2.0
S₂: 200.0

Optimization Criteria
Gmse (Root Mean Square Error)

Select Parameter to Plot
Select Plot

Model Performance
Correlation
Nash Sutcliffe

MM	DD	YYYY	Temp.	Precip.	Snow	Liquid Water	Soil Moisture	Dq	Pot. Evap.	Evap.	S ₁	S ₂	Q obs	Q sim
List	List	Listbox	Temper	Precip	Snow	Liquid W	Soil Moistu	Dq	Pot. Evap.	Evap.	S1	S2	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

RUN

HBV-EDU

HBV_EDU_V2

Help

Contact:

HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permissions 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
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—
Ormse (Root Mean Square Error)

Select Parameter to Plot
Select Plot

Model Performance

Correlation
Nash Sutcliffe

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
S₁: 2.0
S₂: 200.0

MM DD YYYY Temp. Precip. Snow Liquid Water Soil Moisture Dq Pot. Evap. Evap. S₁ S₂ Q (cfs) Q (sm)

Load Input Files

Load Input Temp. & Precip. Load Monthly Temp. & Evap. Load Observed Q Reset

Run

of simulations: 50
Simulate Q

Model Performance

HBV-EDU

HBV_EDU_V2

Help

Contact

HBV-EDU Ver. 2
AghaKouchak & Emad Habib
For questions and permissions 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
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

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

Select Plot

Select Variable to Plot

MM	DD	YYYY	Temp.	Precip.	Snow	Liquid Water	Soil Moisture	Dq	Pot. Evap.	Evap.	S ₁	S ₂	Q obs	Q sim
List	List	Listbo	Temp	Precip	Snow	Liquid W	Soil Moistu	Dq	Pot. Evap	Evap	S1	S2	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 (Version 3)

HBV_EDU_V3

Help

Contact

HBV-EDU Ver. 3 - 02/12/2011
 Amir AghaKouchak & Emad Habib
 For questions and permissions contact:
 Dr. Amir AghaKouchak (amir.a@uci.edu)
 OR Dr. Emad Habib (habib@louisiana.edu)

Model Parameters

Parameters	Bounds	Optimal
DD	3 7	6.74957
FC	100 200	195.96
Beta	1 7	2.10024
C	0.01 0.07	0.0372456
K_0	0.05 0.2	0.0705676
L	2 5	4.64267
K_1	0.01 0.1	0.0825608
K_2	0.001 0.05	0.0063617
K_p	0.001 0.05	0.0159771
PWP	90 180	168.579

Watershed Area & Snow Melt Thr.

Area	410
T_1	0

Initial Values

Snow	0
Soil Moisture	100
S_1	3
S_2	10

Input Data Based on Monthly Climatological Data

Monthly Temp.	Monthly PE	Daily PE
0	0	0
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

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, Curriculum, and Laboratory Improvement (CCLI) Grant DUE-0737073.

Optimization Criteria

Grmse (Root Mean Square Error)

Select Parameter to Plot

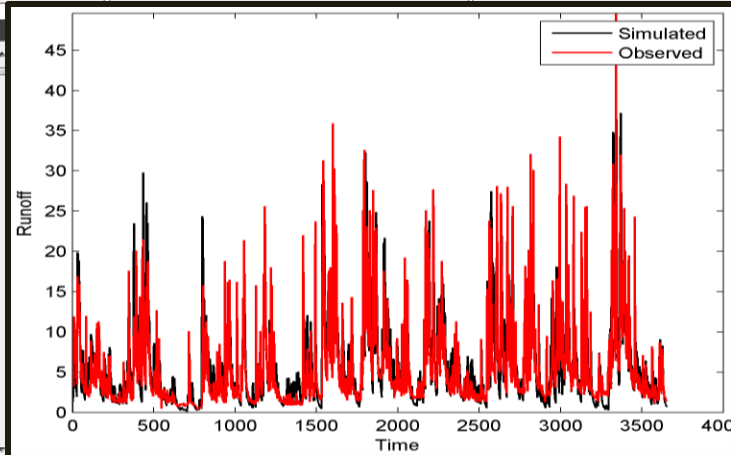
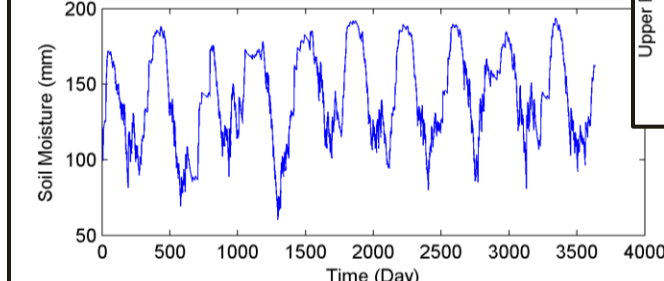
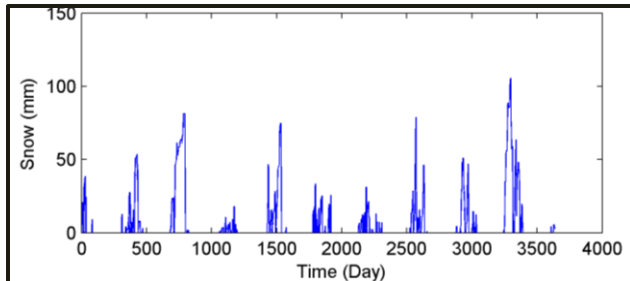
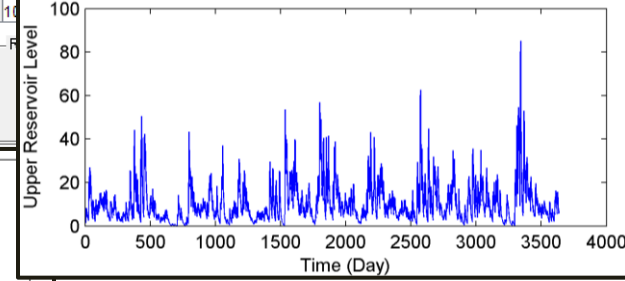
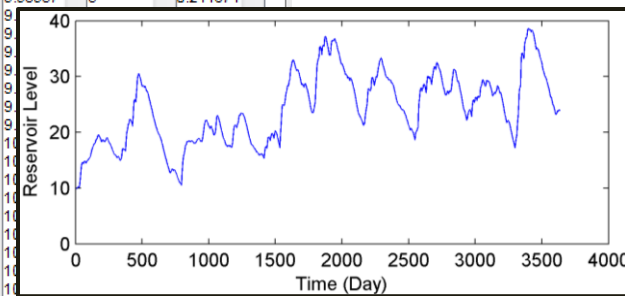
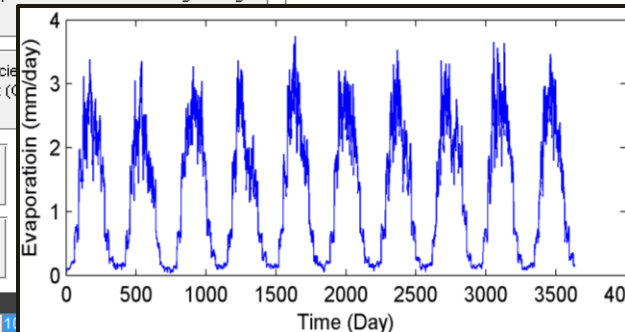
Snow Plot

MM DD YYYY

1	1	1991
1	2	1991
1	3	1991
1	4	1991
1	5	1991
1	6	1991
1	7	1991
1	8	1991
1	9	1991
1	10	1991
1	11	1991
1	12	1991
1	13	1991
1	14	1991
1	15	1991
1	16	1991
1	17	1991
1	18	1991
1	19	1991
1	20	1991
1	21	1991
1	22	1991
1	23	1991

Load Input Files

Load Input Temp. & Precip.	Load Monthly Temp. & Evap.	Load Observed Q	Reset
----------------------------	----------------------------	-----------------	-------



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.





GIDMaPS: Global Integrated Drought Monitoring and Prediction System



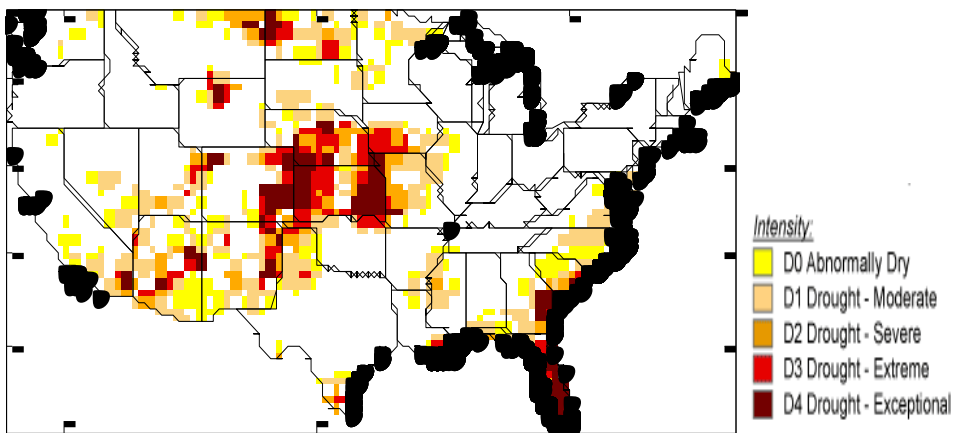
Multi-Index Drought Monitoring



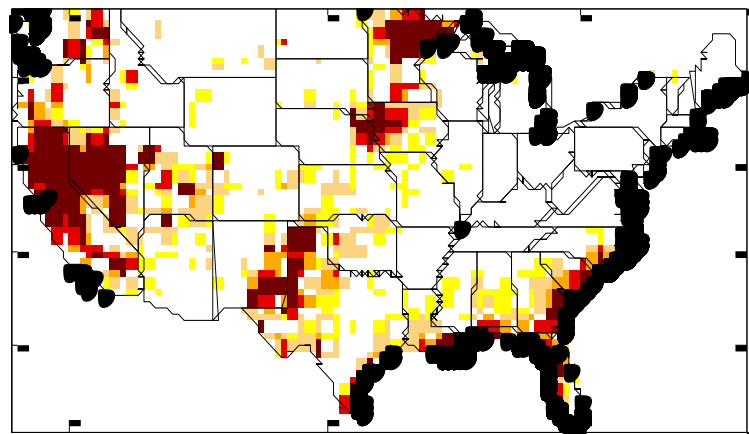
Different drought indices based on different climate variables (e.g., Precipitation, soil moisture):

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

SPI 2012-1



SSI 2012-1



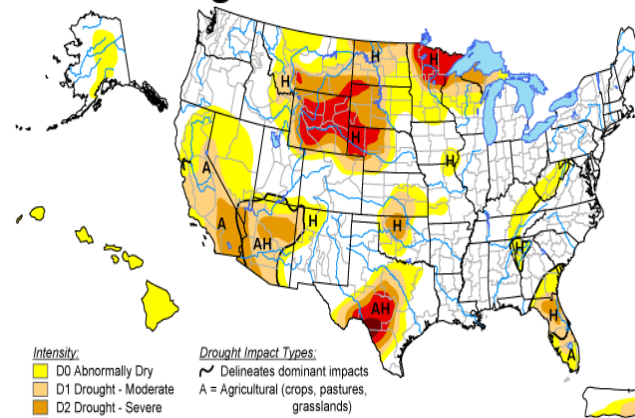


Multi-Index Drought Monitoring



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

U.S. Drought Monitor January 30, 2007 Valid 7 a.m. EST



Intensity:

- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

Drought Impact Types:

- ~ Delineates dominant impacts
- A = Agricultural (crops, pastures, grasslands)
- H = Hydrological (water)

The Drought Monitor focuses on broad-scale conditions.
Local conditions may vary. See accompanying text summary
for forecast statements.

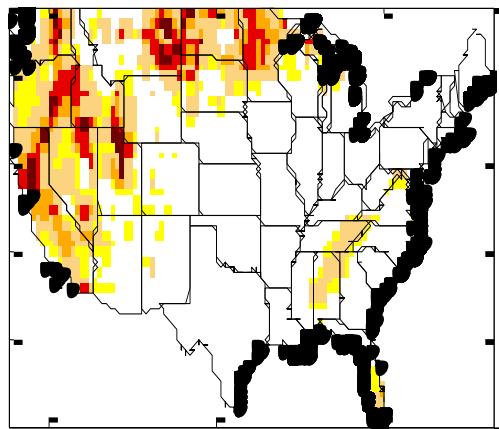
<http://drought.unl.edu/dm>



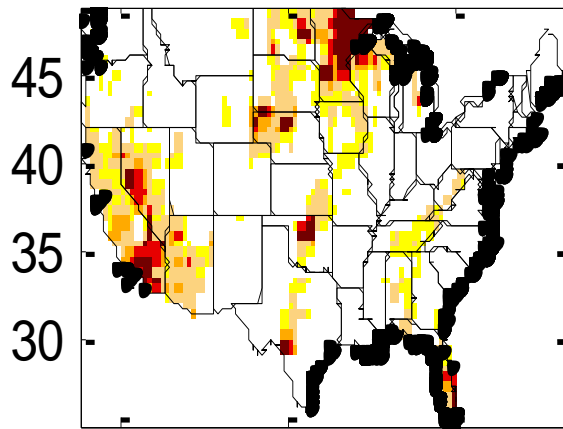
Released Thursday, February 1, 2007

Author: Brian Fuchs, National Drought Mitigation Center

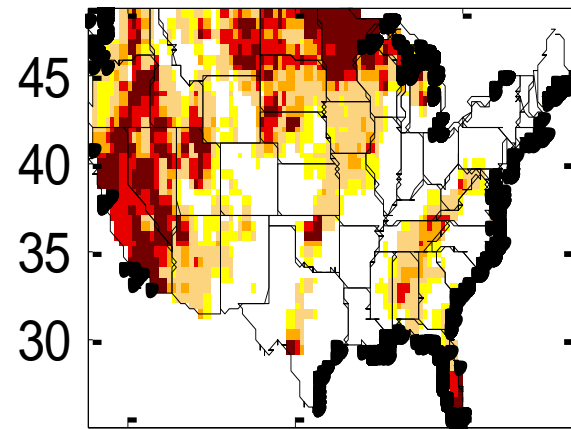
SPI 2007-1



SSI 2007-1



MSDI 2007-1





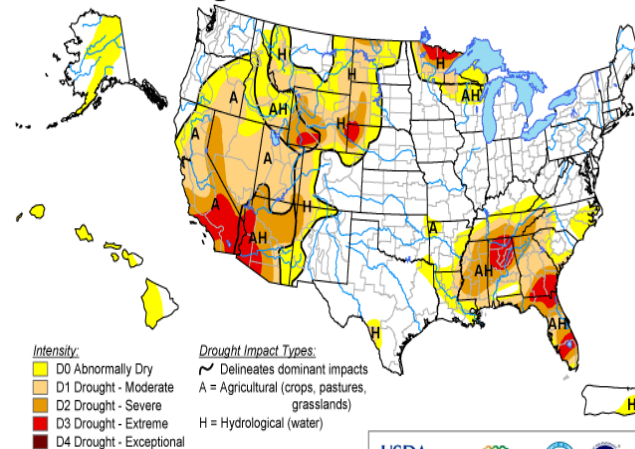
Multi-Index Drought Monitoring



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

U.S. Drought Monitor

May 1, 2007
Valid 8 a.m. EDT



Intensity:

- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

Drought Impact Types:

- ✓ Delineates dominant impacts
- A = Agricultural (crops, pastures, grasslands)
- H = Hydrological (water)

The Drought Monitor focuses on broad-scale conditions.
Local conditions may vary. See accompanying text summary
for forecast statements.

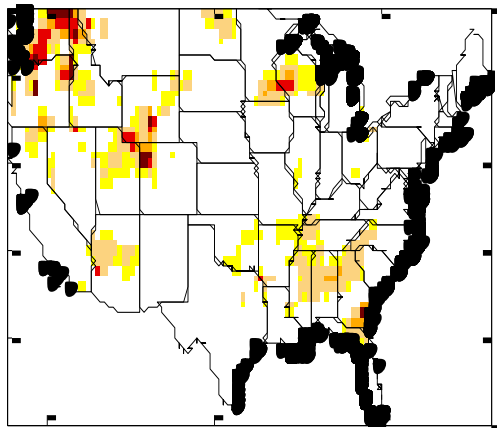


Released Thursday, May 3, 2007

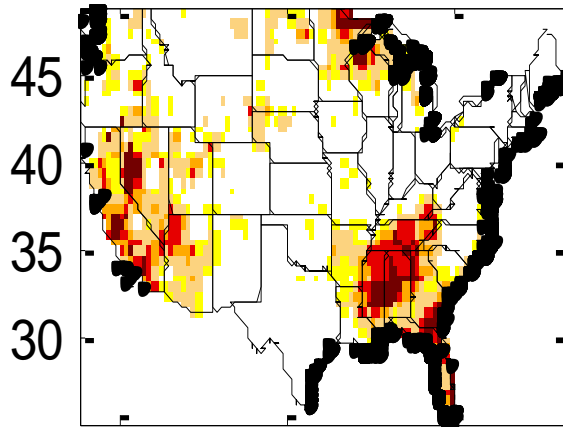
<http://drought.unl.edu/dm>

Author: Brian Fuchs, National Drought Mitigation Center

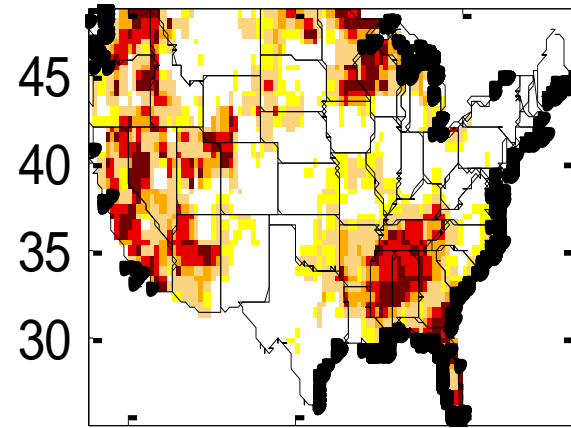
SPI 2007-4



SSI 2007-4



MSDI 2007-4



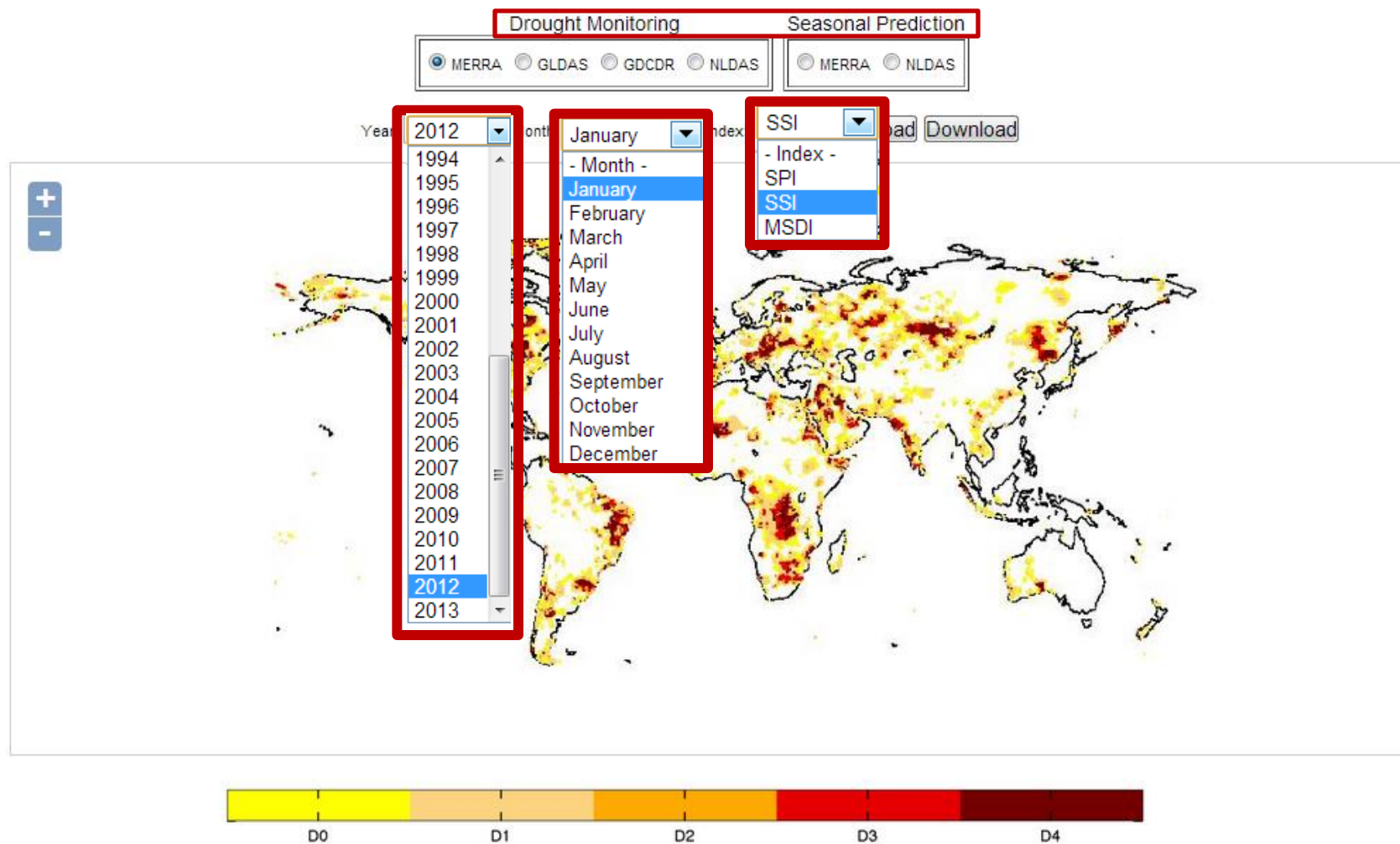


GIDMaPS: Global Integrated Drought Monitoring and Prediction System



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

Global Integrated Drought Monitoring and Prediction System (GIDMaPS)





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



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

Global Integrated Drought Monitoring and Prediction System (GIDMaPS)

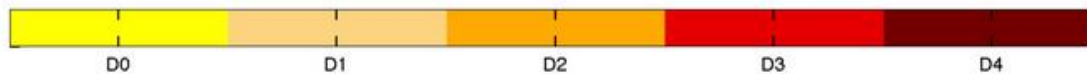
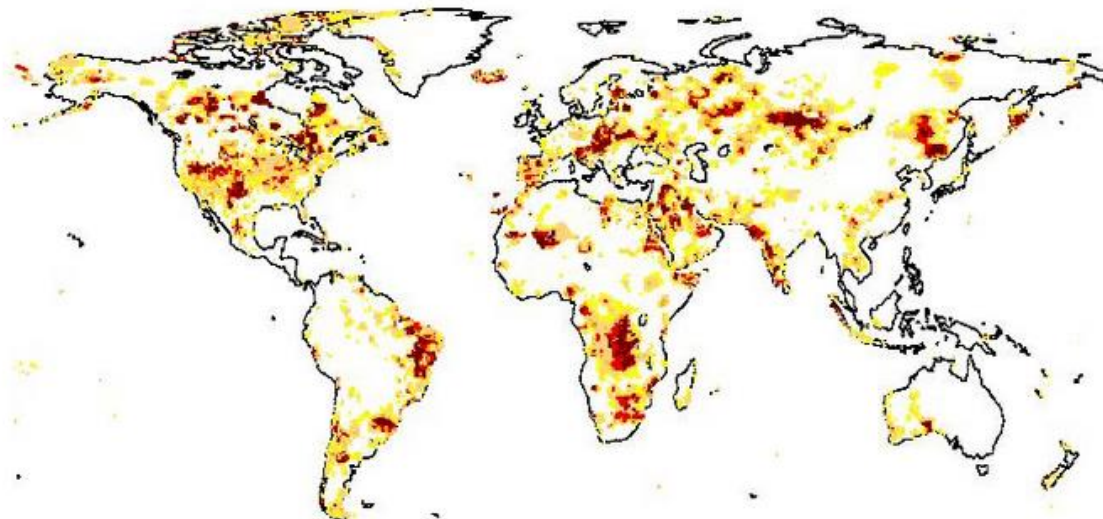
Drought Monitoring

☒ MERRA ☐ GLDAS ☐ GDCDR ☐ NLDAS

Seasonal Prediction

☐ MERRA ☐ NLDAS

Year: 2012 Month: August Index: SSI Load Download





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

Global Integrated Drought Monitoring and Prediction System (GIDMaPS)

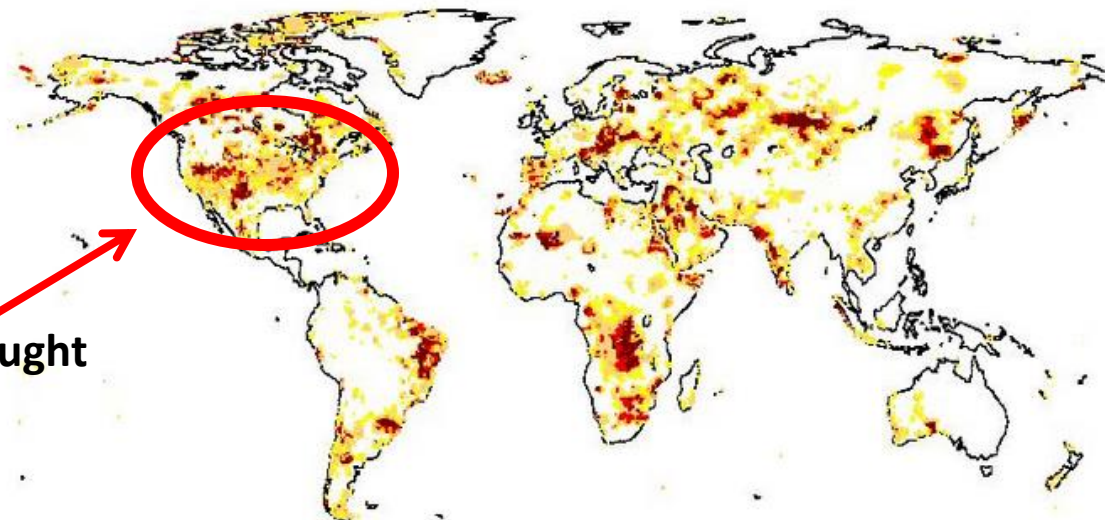
Drought Monitoring

☒ MERRA ☐ GLDAS ☐ GDCDR ☐ NLDAS

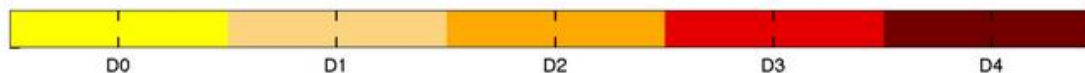
Seasonal Prediction

☐ MERRA ☐ NLDAS

Year: 2012 Month: August Index: SSI Load Download



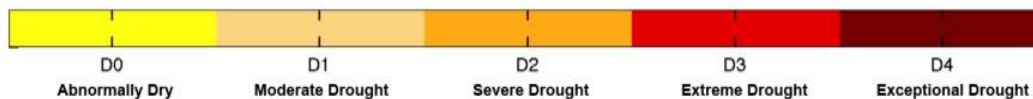
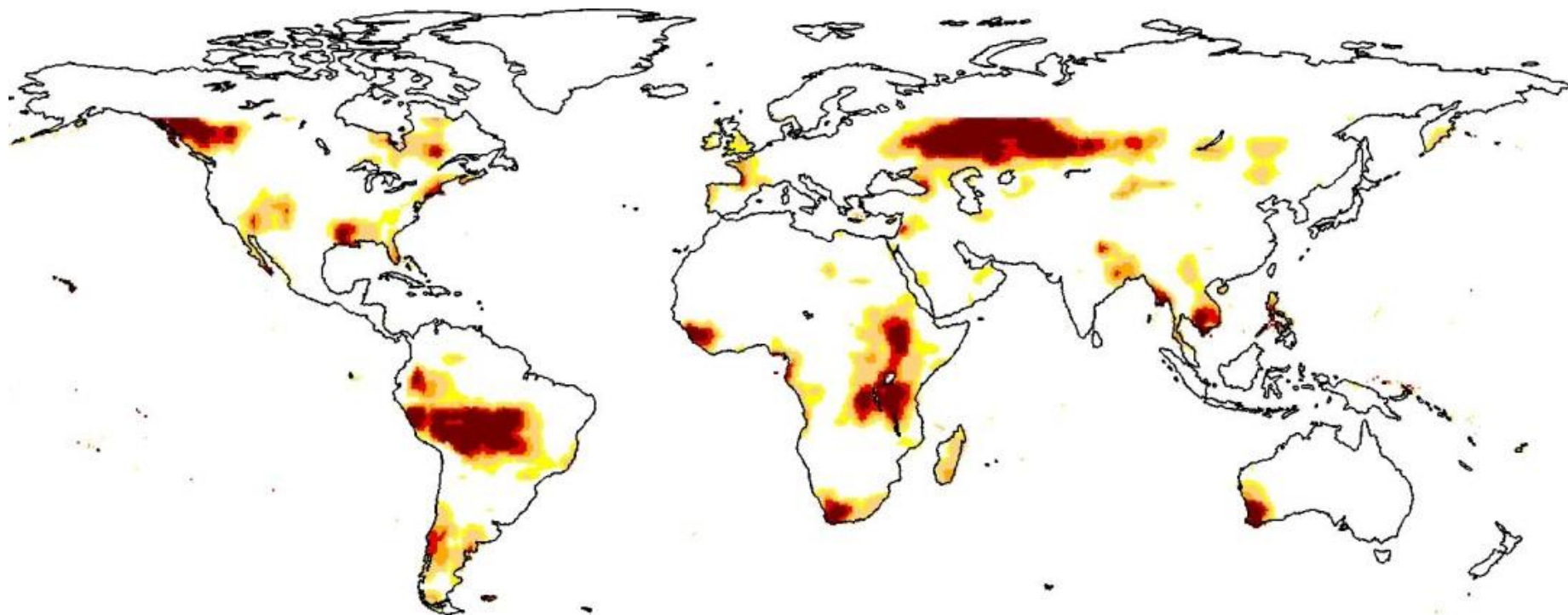
Summer 2012 Drought





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

2010, SPI, GDCDR (PERSIANN combined with GPCP)

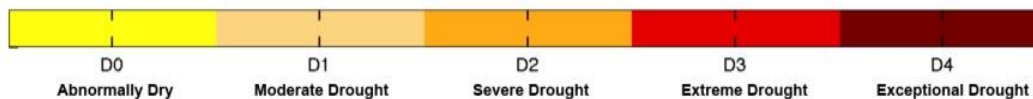
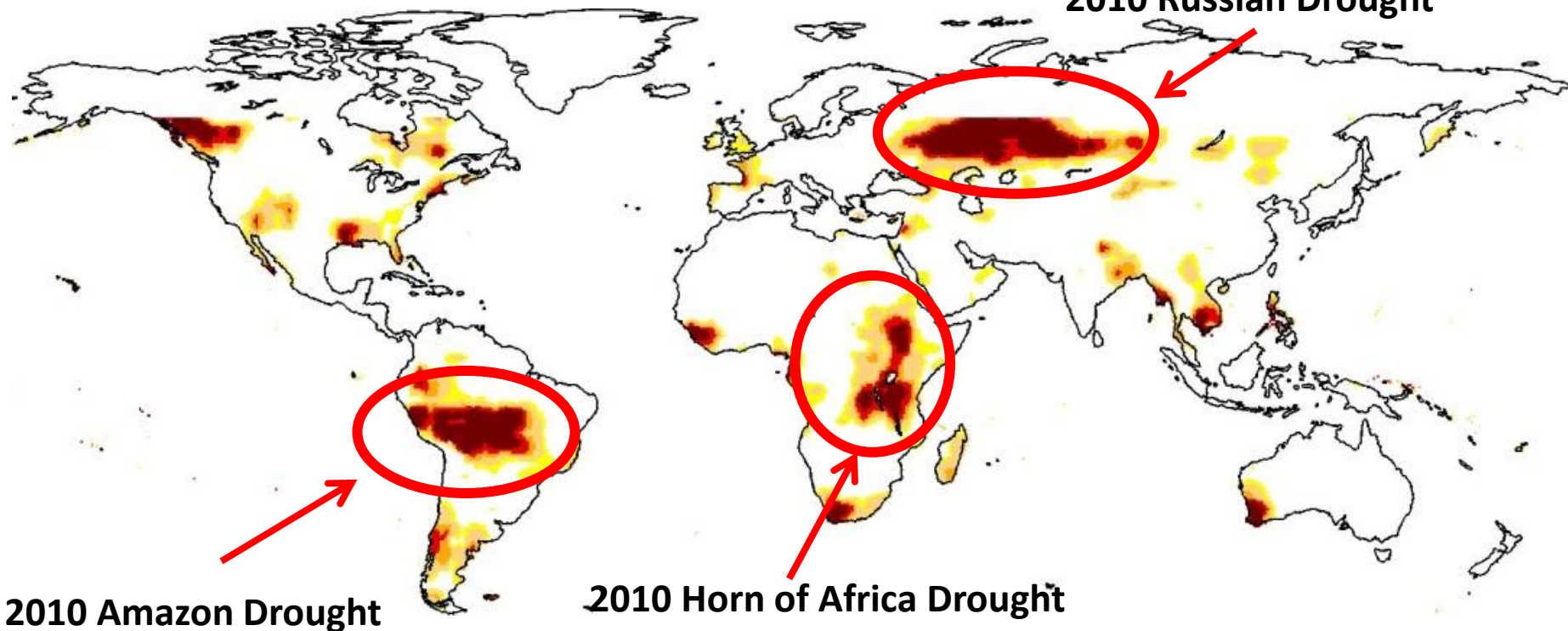




<http://drought.eng.uci.edu/>

2010, SPI, GDCDR

2010 Russian Drought





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

Environ. Res. Lett. 7 (2012) 044037 (8pp)

ENVIRONMENTAL RESEARCH LETTERS

doi:10.1088/1748-9326/7/4/044037

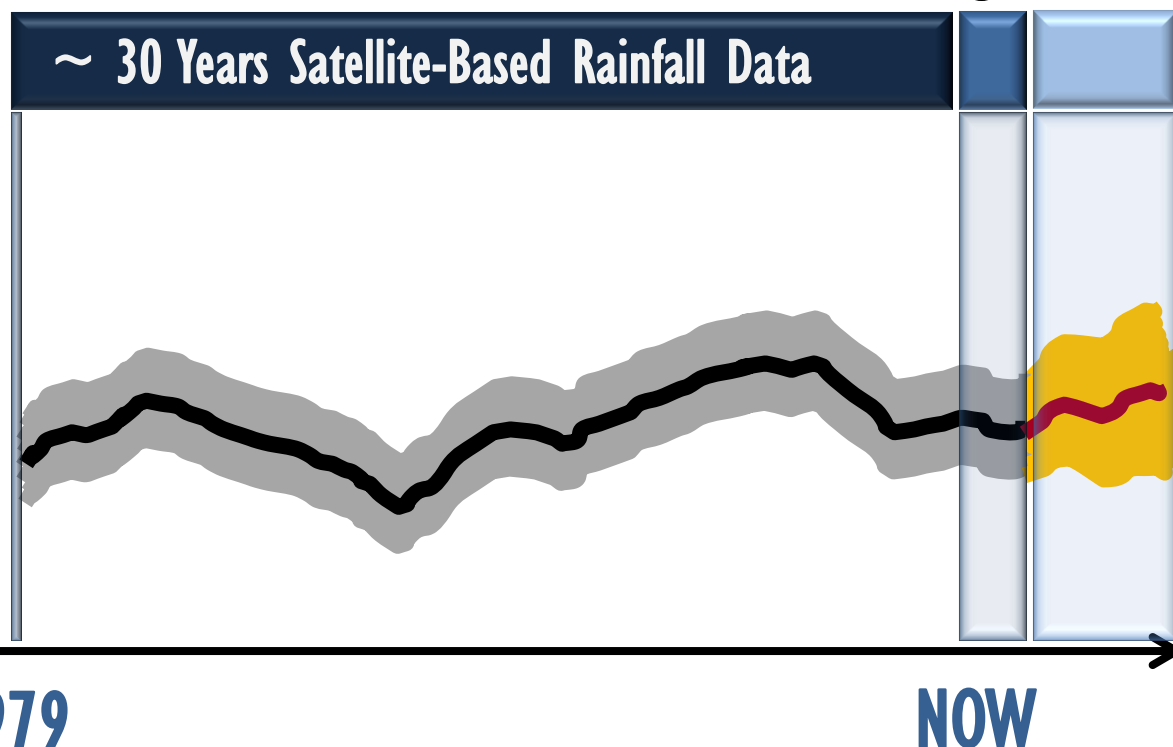
A near real-time satellite-based global drought climate data record

Amir AghaKouchak and Navid Nakhjiri

University of California Irvine, E4130 Engineering Gateway Irvine, CA 92697, USA

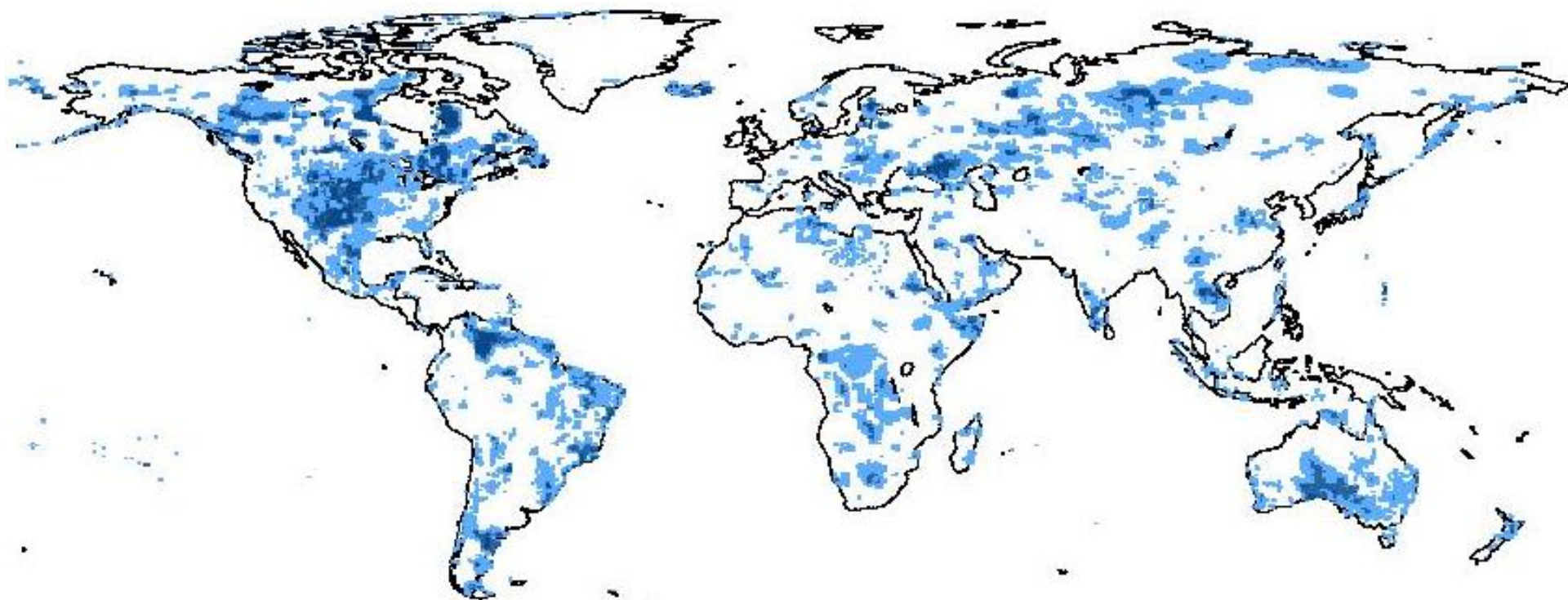
E-mail: amir.a@uci.edu and nnakhjir@uci.edu

~ 30 Years Satellite-Based Rainfall Data





March 2013



Likelihood of Drought Persistence



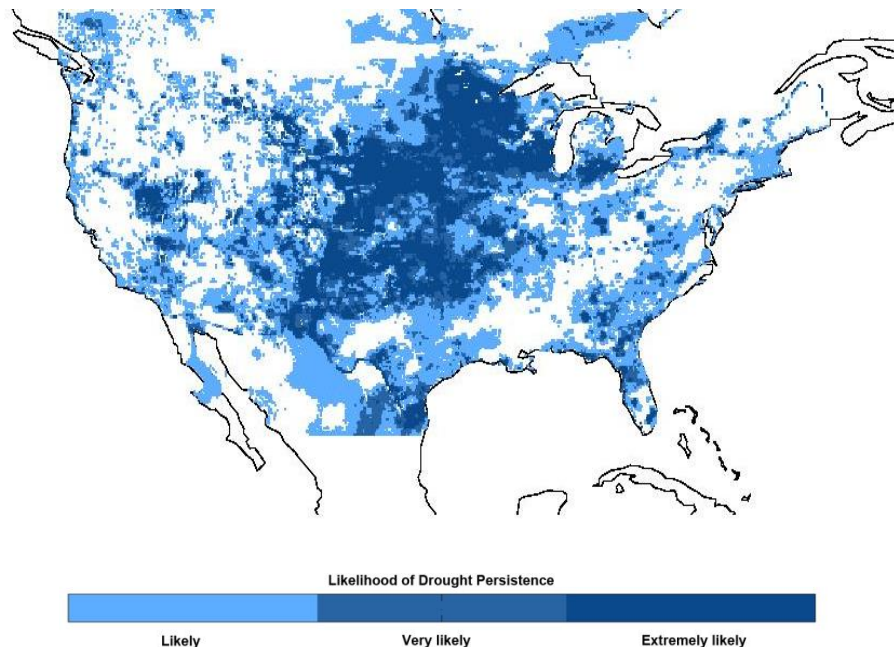
Likely

Very likely

Extremely likely

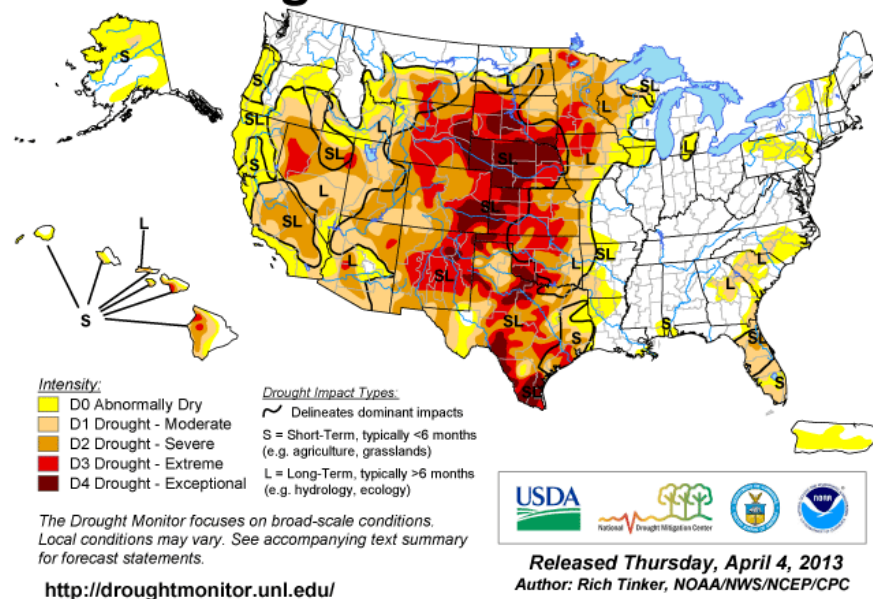


March 31, 2013



U.S. Drought Monitor

April 2, 2013
Valid 7 a.m. EDT



The probability values of the drought prediction component are converted to a 3-category drought likelihood measure:

- (a) drought likely to persist ($\geq 70\%$ probability)
- (b) drought very likely to persist ($\geq 90\%$ probability)
- (a) drought extremely likely to persist ($\geq 95\%$ 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 Ratio (VFAR), Volumetric Missed Index (VMI), and Volumetric Critical Success Index (VCSI).

