Experiences Using Windows Azure to Calibrate Watershed Models

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University of Virginia

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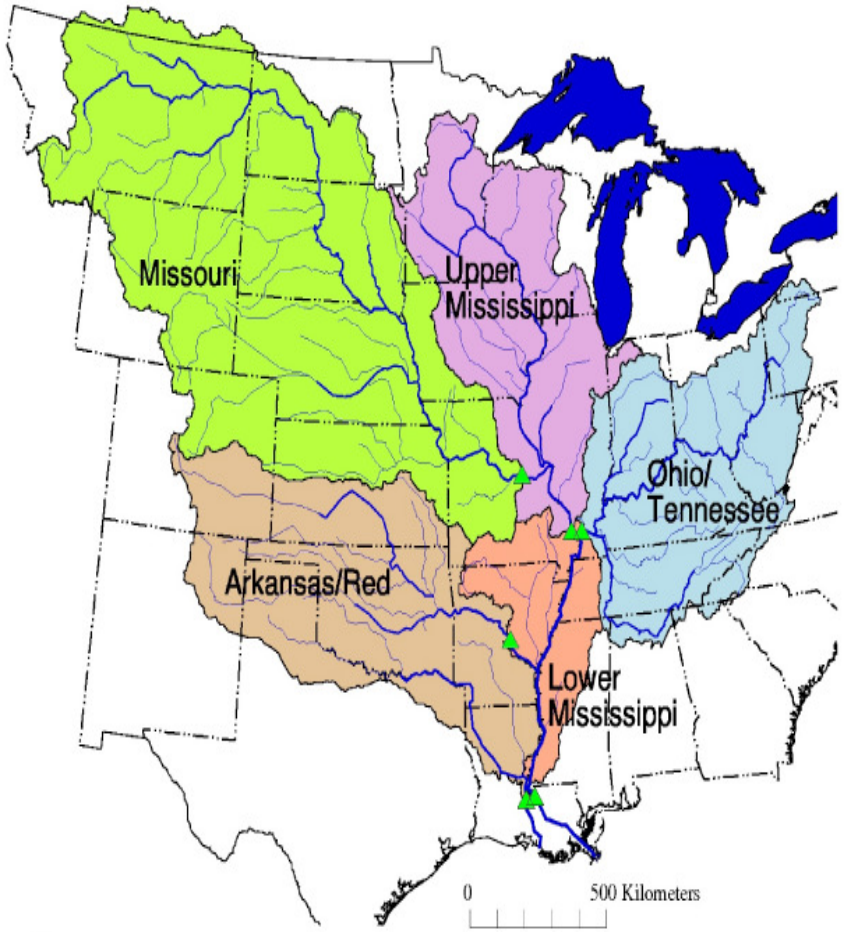
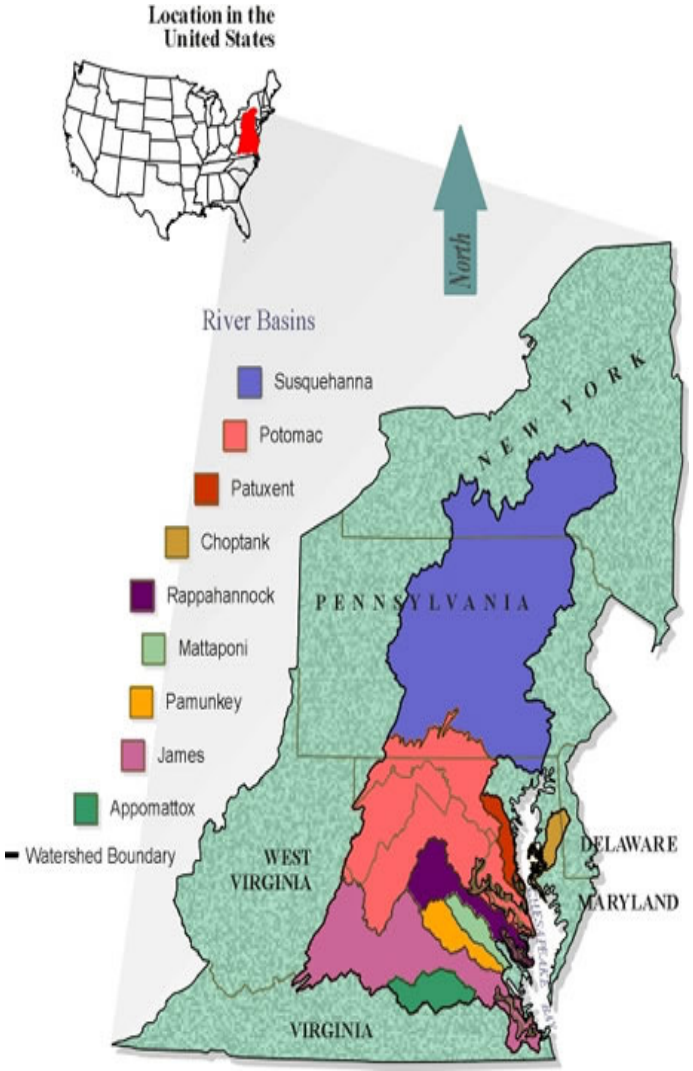
University of South Carolina

Example Large Watersheds

Mississippi River Watershed

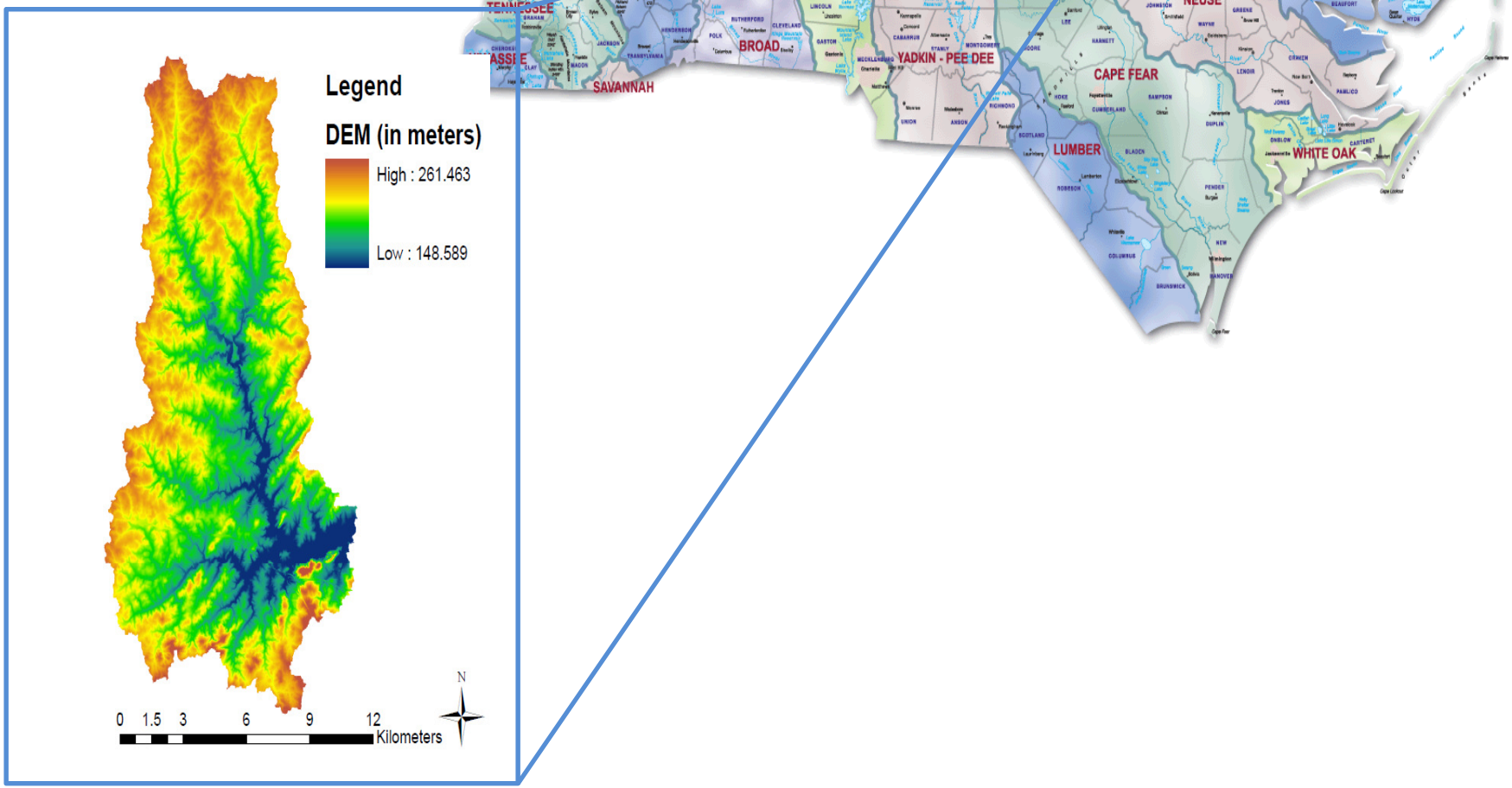


Chesapeake Bay Watershed



Typical Scale of Watershed Models

Eno River near Durham, NC



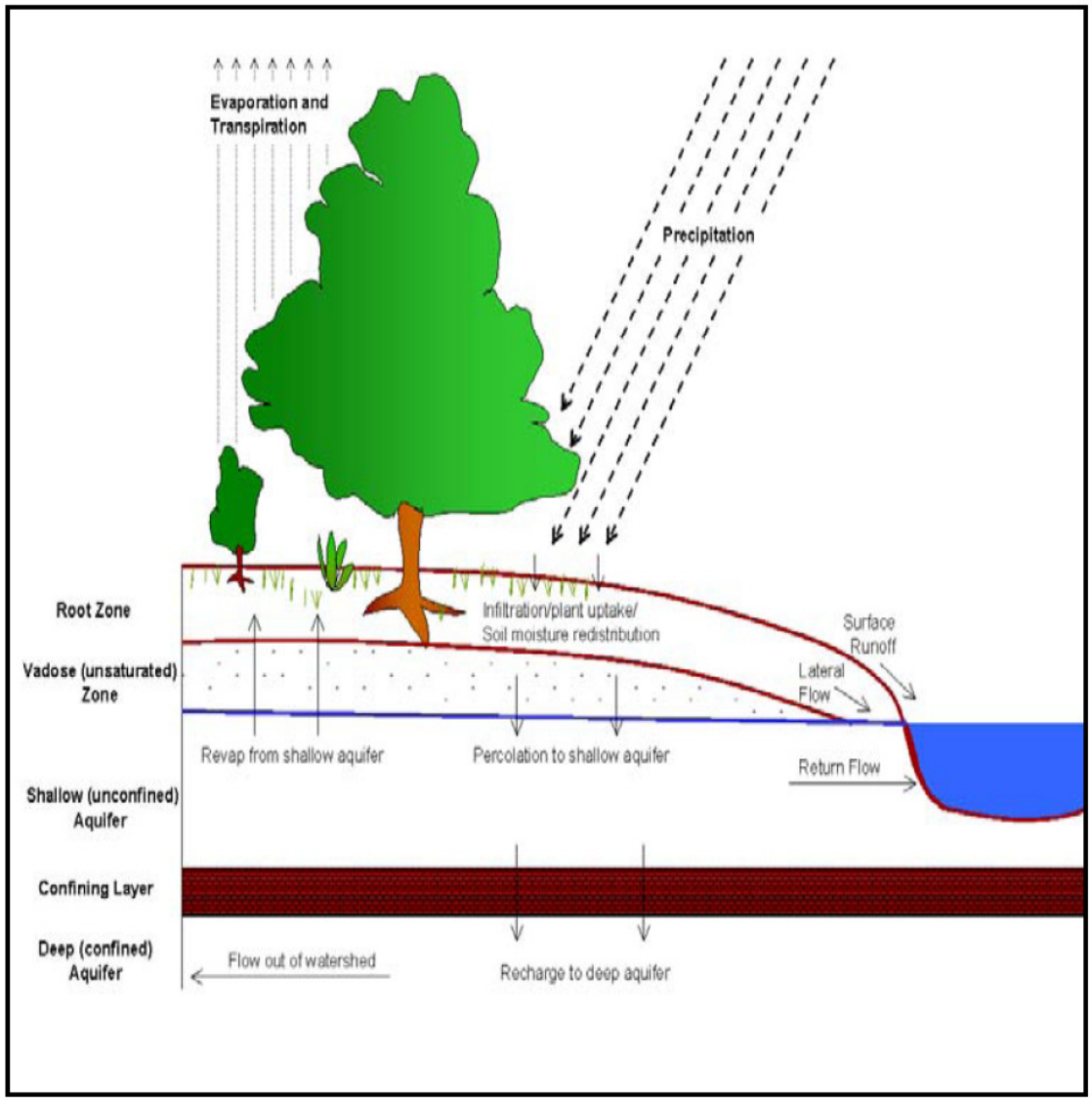
Scale

- Mississippi: 1,245,000 sq mi (3,220,000 km^2)
- Chesapeake: 64,000 sq mi (166,000 km^2)
- Eno (our case study watershed): 66 sq mi (171 km^2)

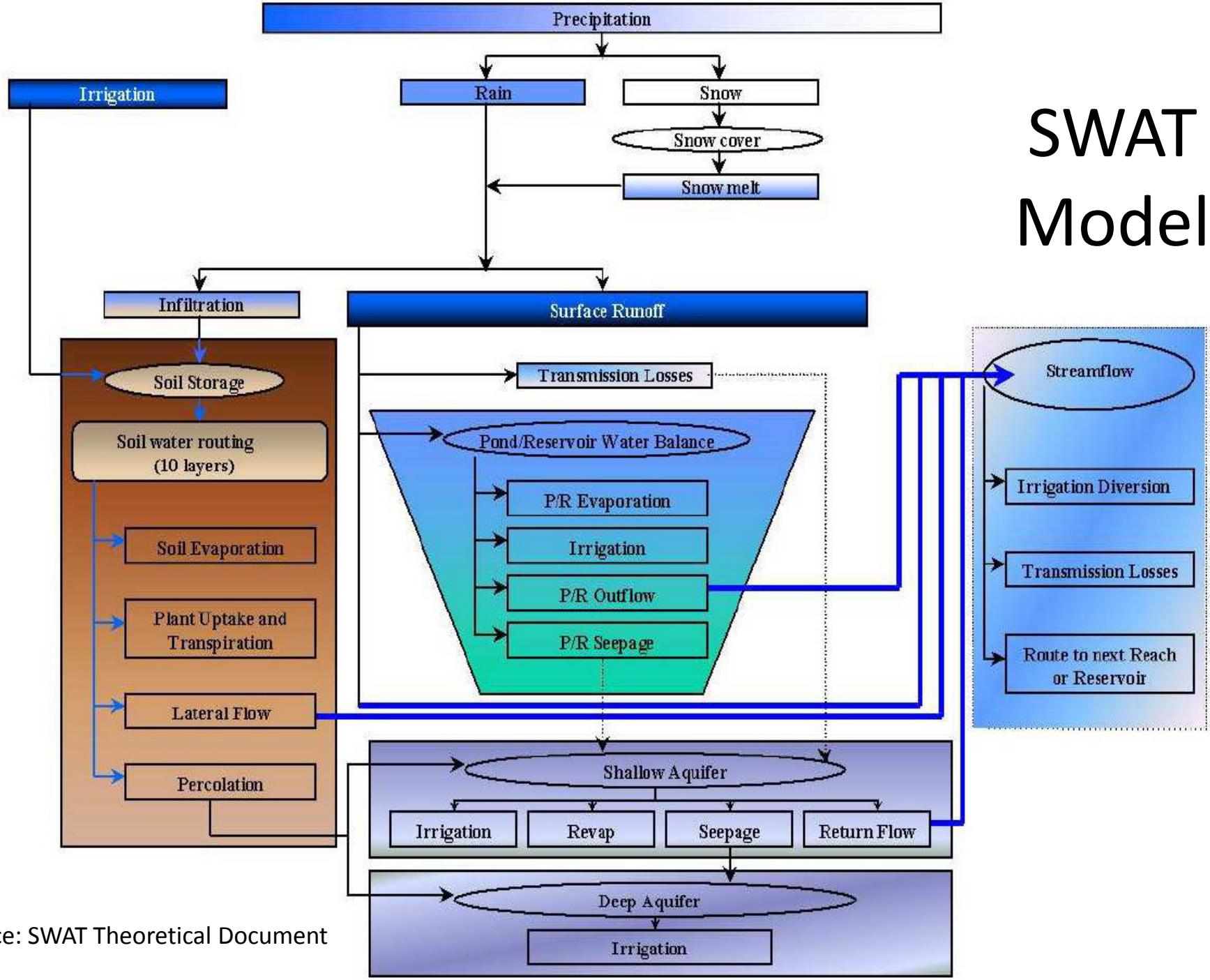
Eno to Chesapeake (~ 1,000 times)

Eno to Mississippi (~ 20,000 times)

Watershed Hydrology



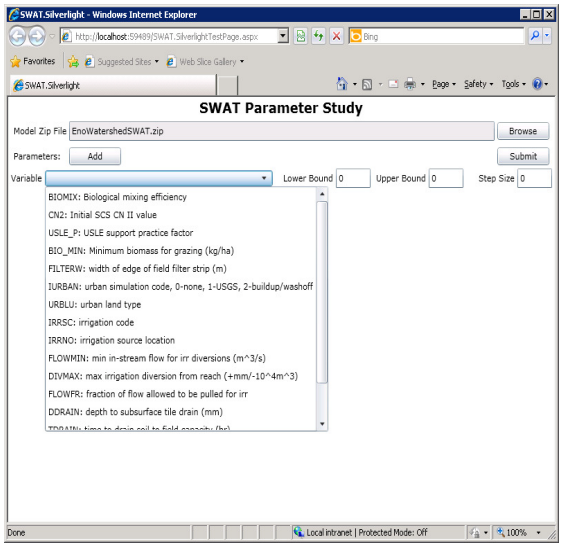
SWAT Model

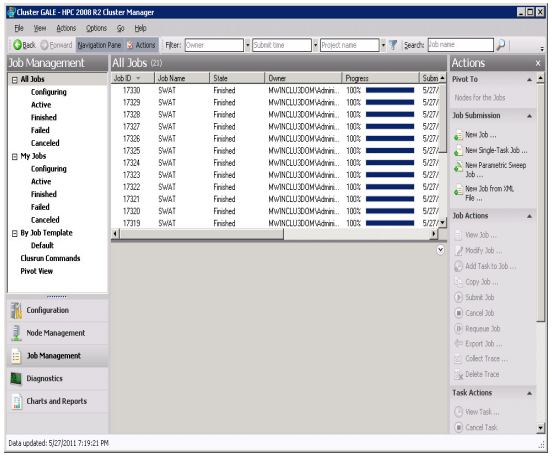


Source: SWAT Theoretical Document

Challenges in Watershed Modeling

- Data Preparation
  - Data exists, but files are large and require preprocessing
- Model Calibration
  - Requires running the model multiple times with varying parameters
- Scale up Model to Large System (Chesapeake, Mississippi)
  - Impractical using current approaches


SWAT.Silverlight - Windows Internet Explorer
SWAT Parameter Study
Model Zip File
EnoWatershedSWAT.zip
Browse
Parameters:
Add
Submit
Variable
Lower Bound
Upper Bound
Step Size
BIOMIX: Biological mixing efficiency
CN2: Initial SCS CN II value
USLE_P: USLE support practice factor
BIO_MIN: Minimum biomass for grazing (kg/ha)
FILTERW: width of edge of field filter strip (m)
IURBAN: urban simulation code, 0-none, 1-USGS, 2-buildup/washoff
URBLU: urban land type
IRRSC: irrigation code
IRRNO: irrigation source location
FLOWMIN: min in-stream flow for irr diversions (m^3/s)
DIVMAX: max irrigation diversion from reach (+mm/-10^4m^3)
FLOWFR: fraction of flow allowed to be pulled for irr
DDRAIN: depth to subsurface tile drain (mm)


Cluster GALE - HPC 2008 R2 Cluster Manager
Job Management
All Jobs
Actions
Configuration
Node Management
Job Management
Diagnostics
Charts and Reports

HPC Cluster

Early Results
(Cloud Futures, June 2011)

	Stage-in	Compute	Total
Scientist laptop	0	55 sec	55 sec
Win2	5 sec	60 sec	65 sec
Azure (ex-large)	53 sec	32 sec	85 sec

Issues
(Cloud Futures, June 2011)

- Windows Azure only or cloudbursting?
- Data storage – where, how?
- Data sharing/reuse policy?
- Task granularity / coding?
- Task synchronization (e.g., MPI)?

Jim Gray, Microsoft Research,
San Francisco, California, July 2003

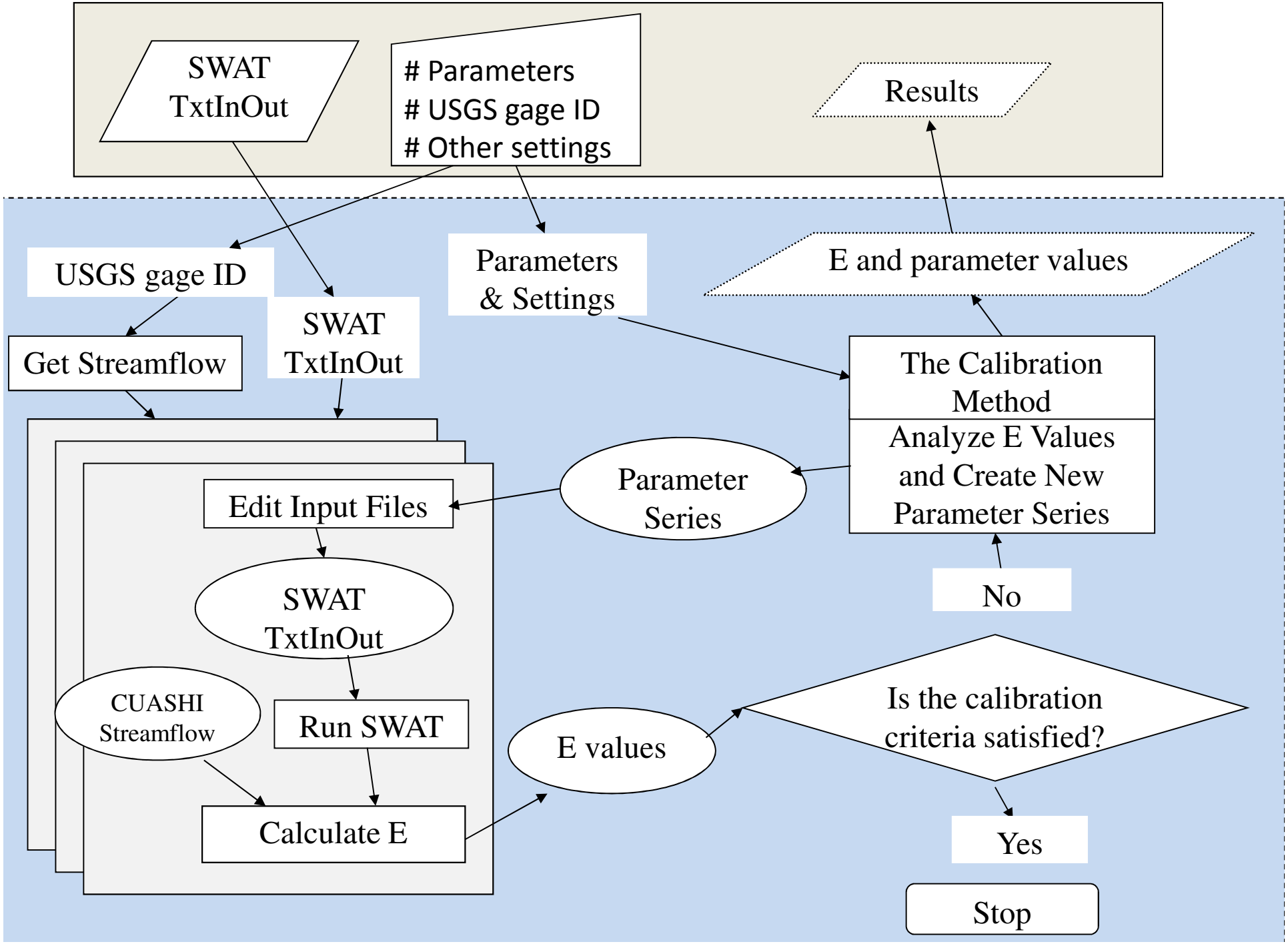
Distributed Computing Economics

JIM GRAY

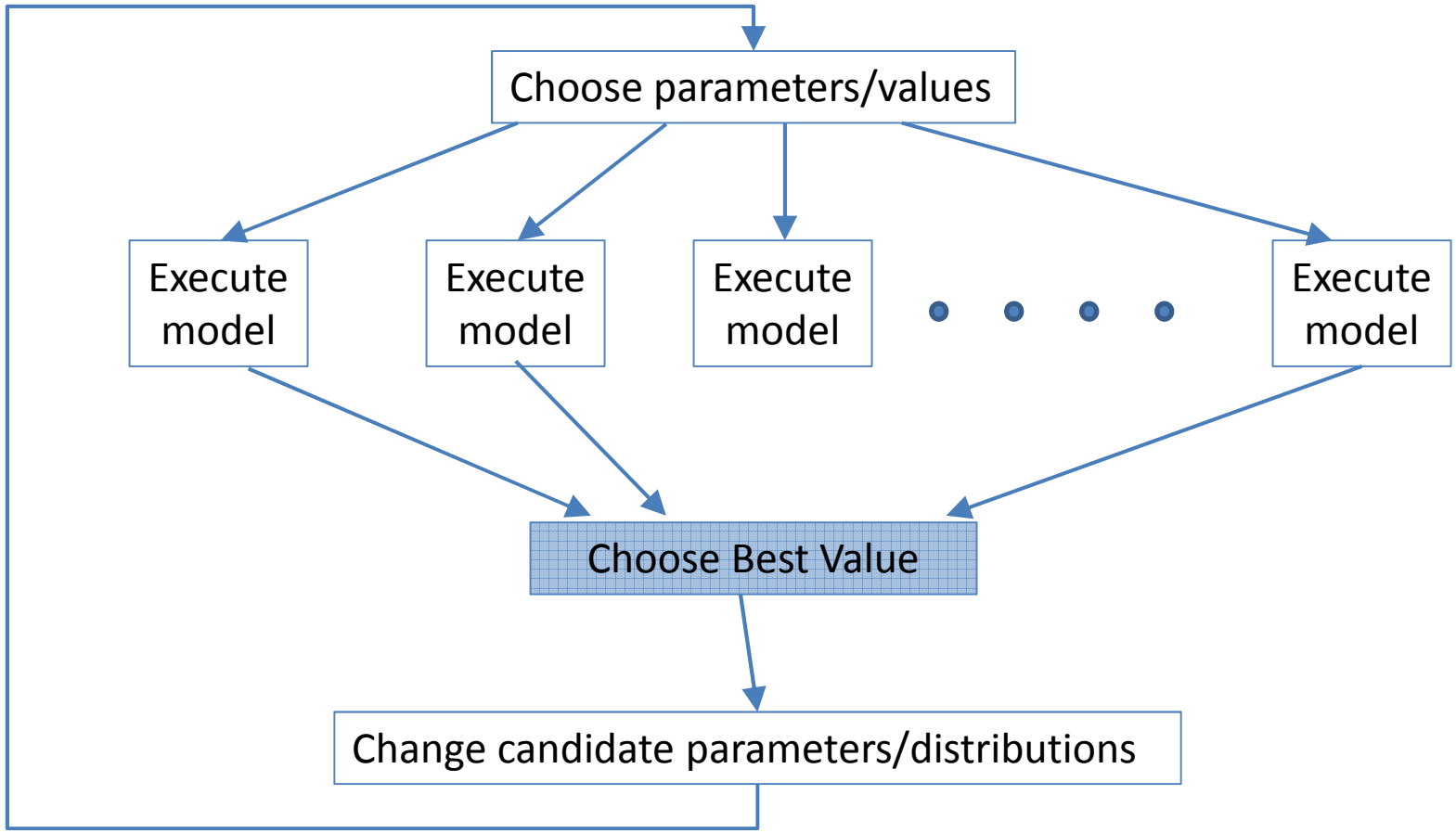
Computing economics are changing. Today there is rough price parity between: (1) one database access; (2) 10 bytes of network traffic; (3) 100,000 instructions; (4) 10 bytes of disk storage; and (5) a megabyte of disk bandwidth. This has implications for how one structures Internet-scale distributed computing: one puts computing as close to the data as possible in order to avoid expensive network traffic.

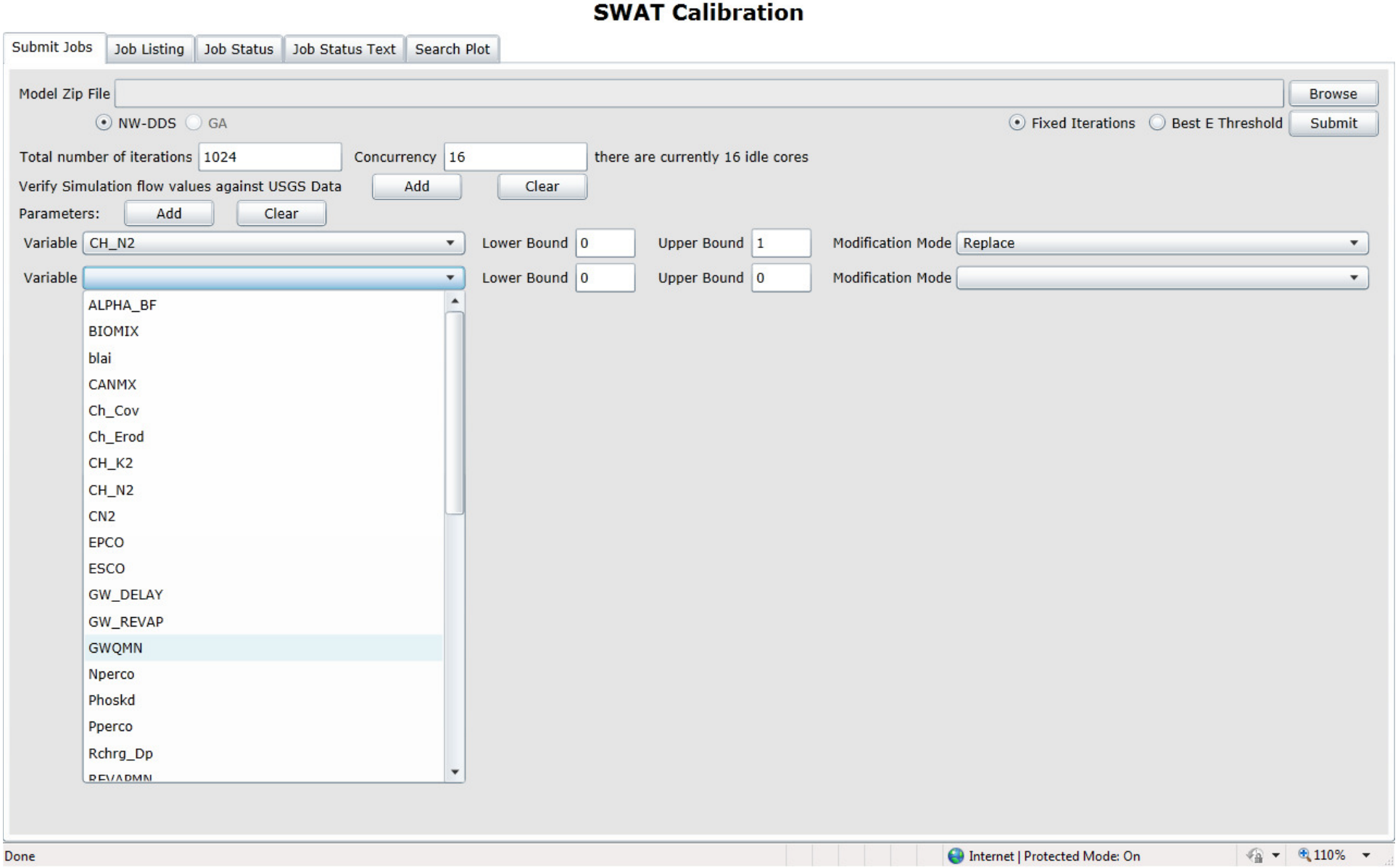
THE COST OF COMPUTING

Computing is free. The world's most powerful computer is free (SETI@Home is a 54-teraflop machine).[1] Google freely provides a trillion searches per year to the world's largest online database (two petabytes). Hotmail freely carries a trillion e-mail messages per year. Amazon.com offers a free book-search tool. Many sites offer free news and other free content. Movies, sports events, concerts, and entertainment are freely available via television.


SWAT TxtInOut
Parameters
USGS gage ID
Other settings
Results
USGS gage ID
Parameters & Settings
E and parameter values
Get Streamflow
SWAT TxtInOut
The Calibration Method
Analyze E Values and Create New Parameter Series
Parameter Series
Edit Input Files
SWAT TxtInOut
CUASHI Streamflow
Run SWAT
Calculate E
E values
Is the calibration criteria satisfied?
No
Yes
Stop

P-DDS


Choose parameters/values
Execute model
Execute model
Execute model
Execute model
Choose Best Value
Change candidate parameters/distributions


SWAT Calibration
Submit Jobs
Job Listing
Job Status
Job Status Text
Search Plot
Model Zip File
Browse
NW-DDS
GA
Fixed Iterations
Best E Threshold
Submit
Total number of iterations
1024
Concurrency
16
there are currently 16 idle cores
Verify Simulation flow values against USGS Data
Add
Clear
Parameters:
Add
Clear
Variable
CH_N2
Lower Bound
0
Upper Bound
1
Modification Mode
Replace
Variable
Lower Bound
0
Upper Bound
0
Modification Mode
ALPHA_BF
BIOMIX
blai
CANMX
Ch_Cov
Ch_Erod
CH_K2
CH_N2
CN2
EPCO
ESCO
GW_DELAY
GW_REVAP
GWQMN
Nperco
Phoskd
Pperco
Rchrg_Dp
Done
Internet | Protected Mode: On
110%

SWAT Calibration

Submit Jobs | Job Listing | Job Status | Job Status Text | Search Plot

Load/Refresh

Job ID	Status	Input File	Parameters Calibrated	Best Daily E
69	Done	SWATnoCal_2012_2_21_17_2_49.zip	ALPHA_BF, REVAPMN, GWQMN, CANMX, CN2, Sol_Z, Ave. AW Incl. Rock Frag, ESCO, SURLAG, CH_K2	0
70	Done	AutoCal_test_2012_2_22_11_17_46.zip	ALPHA_BF, REVAPMN, GWQMN, CANMX, CN2, Sol_Z, Ave. AW Incl. Rock Frag, ESCO, SURLAG, CH_K2	0.950795400
71	Done	AutoCal_test_2012_2_22_11_44_40.zip	CANMX, CN2, Ave. AW Incl. Rock Frag, ESCO	0.812586847
72	Failed	SWATnoCal_2012_2_22_13_13_29.zip	ALPHA_BF, REVAPMN, GWQMN, CANMX, CN2, Sol_Z, Ave. AW Incl. Rock Frag, ESCO, SURLAG, CH_K2	0.751560458
73	Done	SWATnoCal_2012_2_23_10_55_57.zip	ALPHA_BF	0.592561975
74	Done	SWATnoCal_2012_2_23_11_4_28.zip	ALPHA_BF, REVAPMN, GWQMN, CANMX, CN2, Sol_Z, Ave. AW Incl. Rock Frag, ESCO, SURLAG, CH_K2	0.753263733
75	Done	SWATnoCal_2012_2_23_12_13_16.zip	ALPHA_BF, REVAPMN, GWQMN, CANMX, CN2, Sol_Z, Ave. AW Incl. Rock Frag, ESCO, SURLAG, CH_K2	0.785117606
76	Done	SWATnoCal_2012_2_24_10_7_34.zip	ALPHA_BF, REVAPMN, GWQMN, CANMX, CN2, Sol_Z, Ave. AW Incl. Rock Frag, ESCO, SURLAG, CH_K2	0.752704232
77	Done	SWATnoCal_2012_2_24_11_53_5.zip	ALPHA_BF, REVAPMN, GWQMN, CANMX, CN2, Sol_Z, Ave. AW Incl. Rock Frag, ESCO, SURLAG, CH_K2	0.761718524
78	Done	SWATnoCal_2012_2_24_14_17_52.zip	ALPHA_BF, REVAPMN, GWQMN, CANMX, CN2, Sol_Z, Ave. AW Incl. Rock Frag, ESCO, SURLAG, CH_K2	0.749799309
79	Done	SWATnoCal_2012_2_24_14_54_10.zip	ALPHA_BF, REVAPMN, GWQMN, CANMX, CN2, Sol_Z, Ave. AW Incl. Rock Frag, ESCO, SURLAG, CH_K2	0.785899864
80	Done	SWATnoCal_2012_2_24_16_55_55.zip	ALPHA_BF, REVAPMN, GWQMN, CANMX, CN2, Sol_Z, Ave. AW Incl. Rock Frag, ESCO, SURLAG, CH_K2	0.785873733
81	Done	SWATnoCal_2012_2_27_11_7_31.zip	ALPHA_BF, REVAPMN, GWQMN, CANMX, CN2, Sol_Z, Ave. AW Incl. Rock Frag, ESCO, SURLAG, CH_K2	0.718144797
82	Failed	SWATnoCal_2012_2_28_14_3_56.zip	ALPHA_BF, REVAPMN, GWQMN, CANMX, CN2, Sol_Z, Ave. AW Incl. Rock Frag, ESCO, SURLAG, CH_K2	0.467343344
84	Failed	SWATnoCal_2012_2_27_11_7_31_2012_3_2_19_24_38.zip	BIOMIX	0
85	Failed	SWATnoCal_2012_2_27_11_7_31_2012_3_3_6_4_3.zip	BIOMIX	0
86	Failed	SWATnoCal_2012_2_27_11_7_31_2012_3_3_6_7_29.zip	BIOMIX	0
87	Done	SWATnoCal_2012_2_27_11_7_31_2012_3_3_6_27_57.zip	BIOMIX	0.578020512
88	Done	SWATnoCal_2012_2_27_11_7_31_2012_3_3_7_9_21.zip	BIOMIX	0.577775339
90	Done	SWATnoCal_2012_2_27_11_7_31_2012_3_3_7_18_8.zip	BIOMIX	0.578035445
91	Done	SWATnoCal_2012_2_27_11_7_31_2012_3_3_8_16_13.zip	BIOMIX	0.108922727
92	Done	SWATnoCal_2012_2_27_11_7_31_2012_3_3_8_31_15.zip	CANMX, Ave. AW Incl. Rock Frag, BIOMIX	0.644082067
93	Done	SWATnoCal_2012_2_27_11_7_31_2012_3_3_9_25_38.zip	CANMX, Ave. AW Incl. Rock Frag, BIOMIX	0.643990437

SWAT Calibration

Submit Jobs | Job Listing | Job Status | Job Status Text | Search Plot

Job ID 215 Load Cancel Refresh

Current best E (daily) 0.5209498978306 Current best parameters [Parameter = CANMX, Value = 5][Parameter = Ave. AW Incl. Rock Frag, Value = 0][Parameter = ESCO, Value = 0.5][Parameter = SU

Best run output file: 7 of 1008 iterations complete. Estimated completion in 01:52:11.0099857.

Job ID	Task ID	Daily Verification Value	Monthly Verification Value	Verification Result
215	1	-1.79769313486232E+308	-1.79769313486232E+308	
215	2	0.435030079124287	0.430177564846467	[Subbasin = 9, Monthly E = 0.430177564846467, Monthly R^2 = 0.492689608758142, Daily E = 0.435030079124287
215	3	-1.79769313486232E+308	-1.79769313486232E+308	
215	4	0.448744819957035	0.440016242695082	[Subbasin = 9, Monthly E = 0.440016242695082, Monthly R^2 = 0.496065138442328, Daily E = 0.448744819957035
215	5	0.51956086430255	0.43099698157476	[Subbasin = 9, Monthly E = 0.43099698157476, Monthly R^2 = 0.503963742286991, Daily E = 0.51956086430255, D
215	6	-1.79769313486232E+308	-1.79769313486232E+308	
215	7	-1.79769313486232E+308	-1.79769313486232E+308	
215	8	0.515377393104625	0.415546753302534	[Subbasin = 9, Monthly E = 0.415546753302534, Monthly R^2 = 0.500532711453686, Daily E = 0.515377393104625
215	9	0.518694240600354	0.426704982246484	[Subbasin = 9, Monthly E = 0.426704982246484, Monthly R^2 = 0.500508918265719, Daily E = 0.518694240600354
215	10	-1.79769313486232E+308	-1.79769313486232E+308	
215	11	-1.79769313486232E+308	-1.79769313486232E+308	
215	12	-1.79769313486232E+308	-1.79769313486232E+308	
215	13	-1.79769313486232E+308	-1.79769313486232E+308	
215	14	-1.79769313486232E+308	-1.79769313486232E+308	
215	15	0.508337718856126	0.431533626688847	[Subbasin = 9, Monthly E = 0.431533626688847, Monthly R^2 = 0.505526188610535, Daily E = 0.508337718856126
215	16	-1.79769313486232E+308	-1.79769313486232E+308	
215	17	-1.79769313486232E+308	-1.79769313486232E+308	
215	18	0.52094989783067	-1.79769313486232E+308	[Subbasin = 9, Monthly E = 0.420503562403376, Monthly R^2 = 0.507040772193582, Daily E = 0.52094989783067,
215	19	-1.79769313486232E+308	-1.79769313486232E+308	
215	20	-1.79769313486232E+308	-1.79769313486232E+308	
215	21	-1.79769313486232E+308	-1.79769313486232E+308	

SWAT Calibration

Submit Jobs | Job Listing | Job Status | Job Status Text | Search Plot

Job ID 215 Load Cancel Refresh

Current best E (daily) 0.546830683921 Current best parameters [Parameter = CANMX, Value = 5][Parameter = Ave. AW Incl. Rock Frag, Value = 0][Parameter = ESCO, Value = 0.5][Parameter = SU

Best run output file: 174 of 1008 iterations complete. Estimated completion in 00:39:34.7430258.

Job ID	Task ID	Daily Verification Value	Monthly Verification Value	Verification Result
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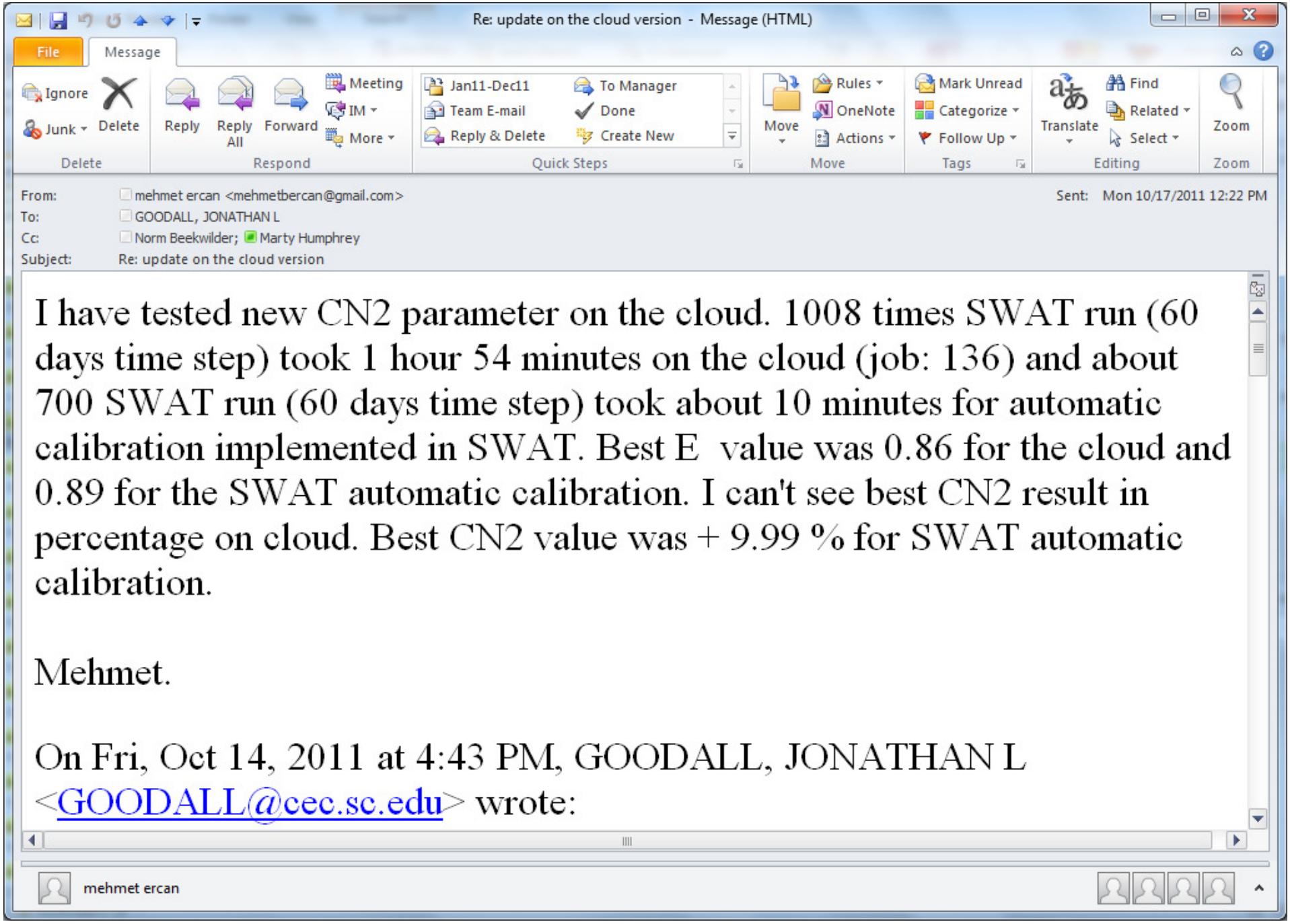
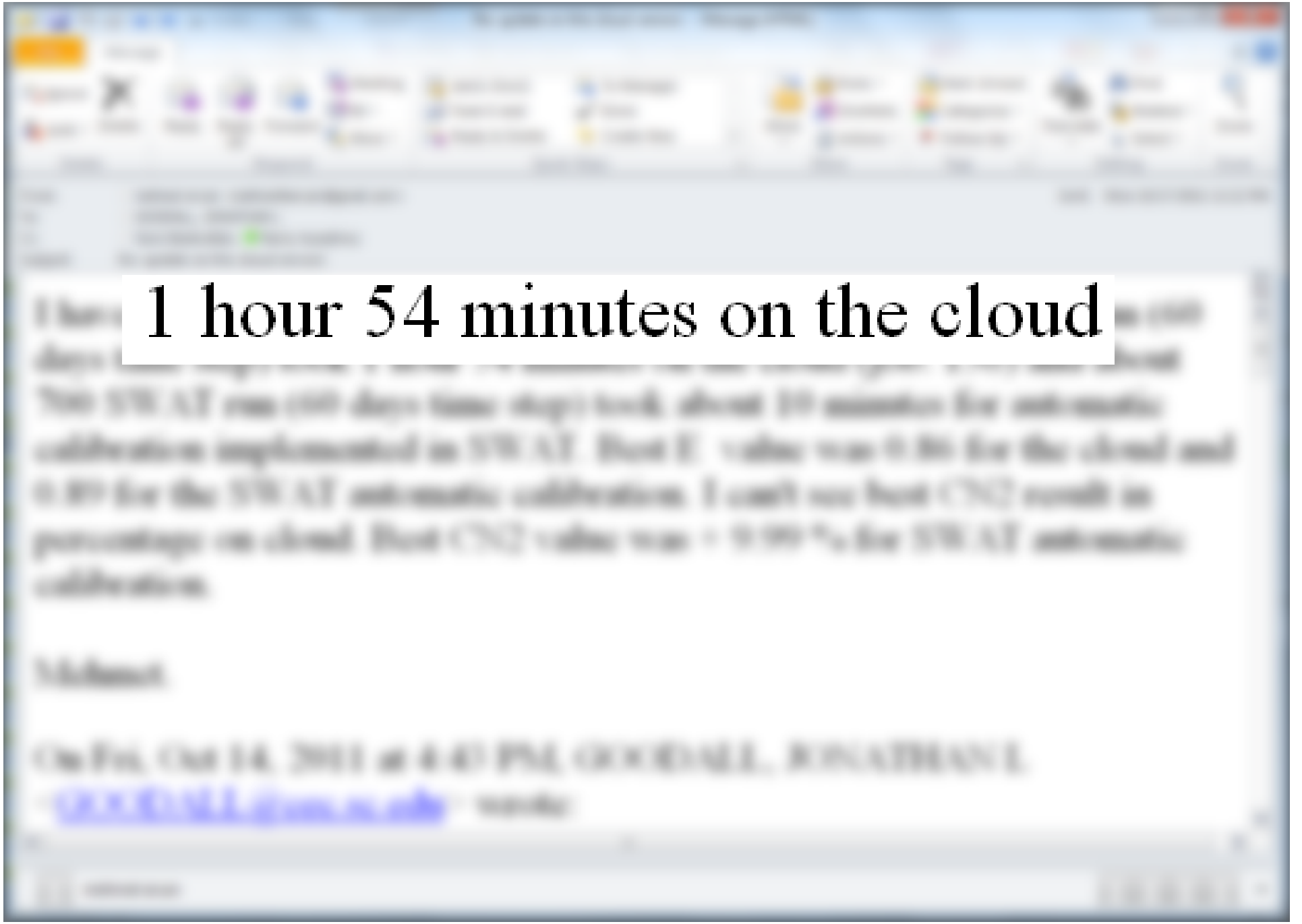
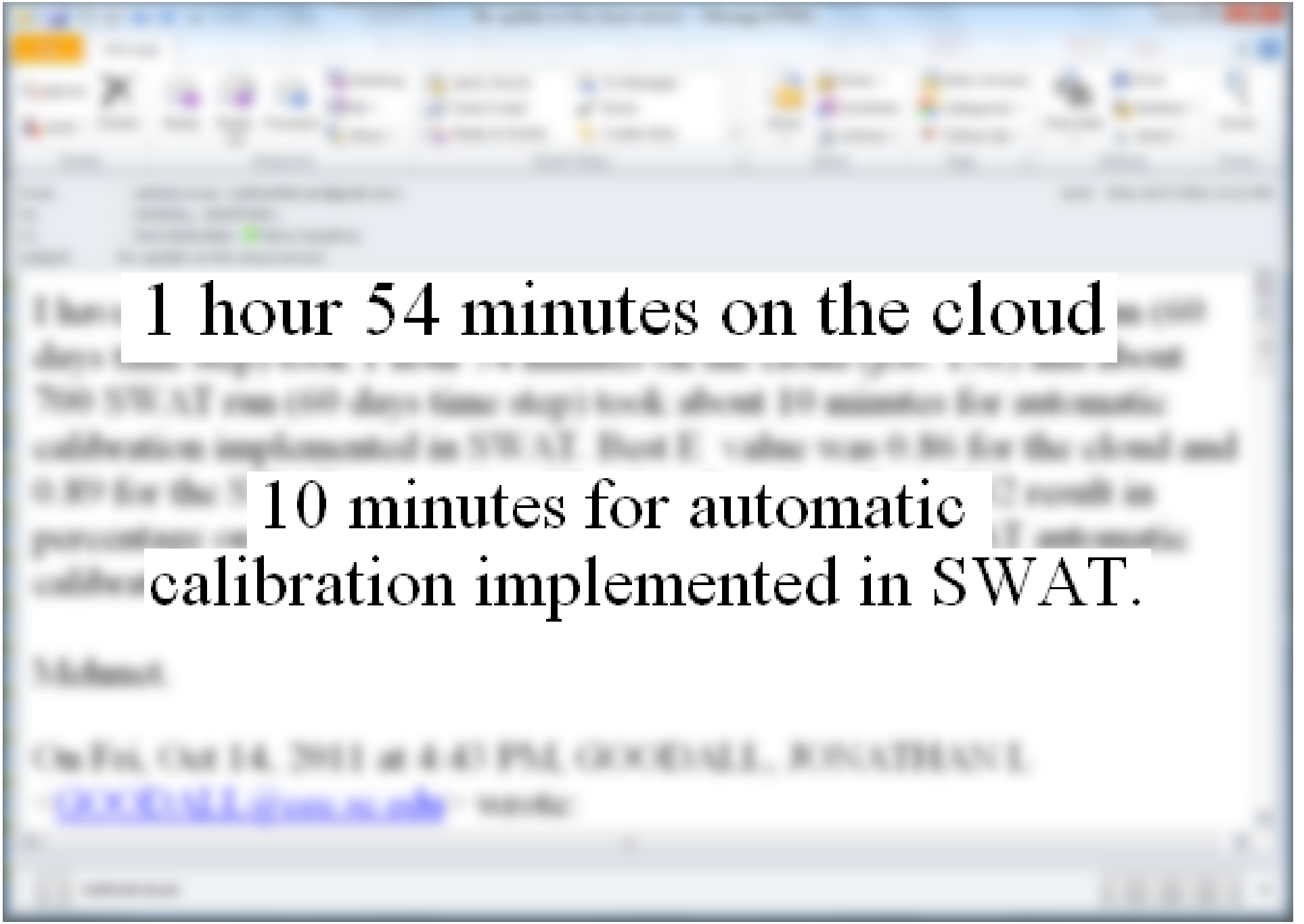
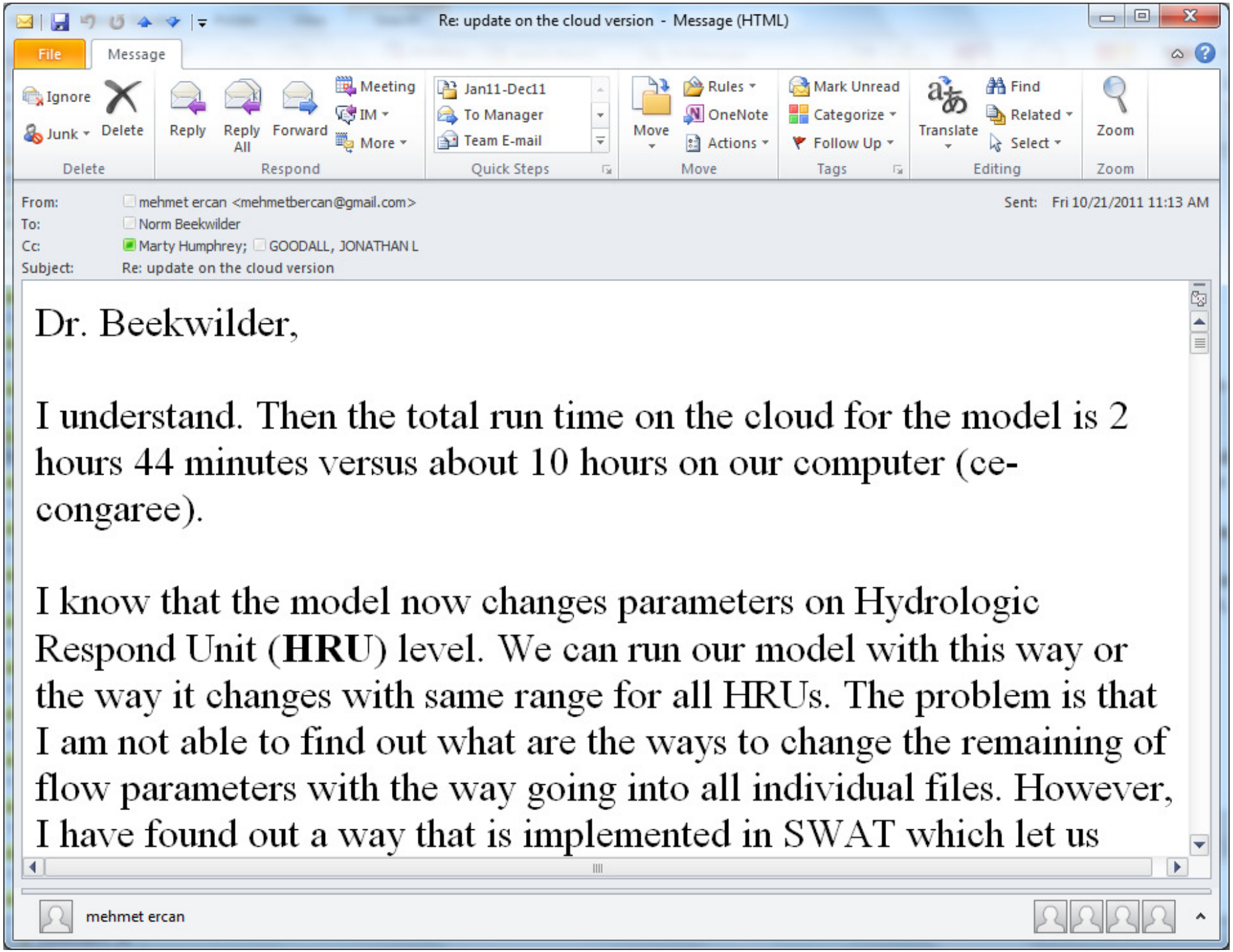
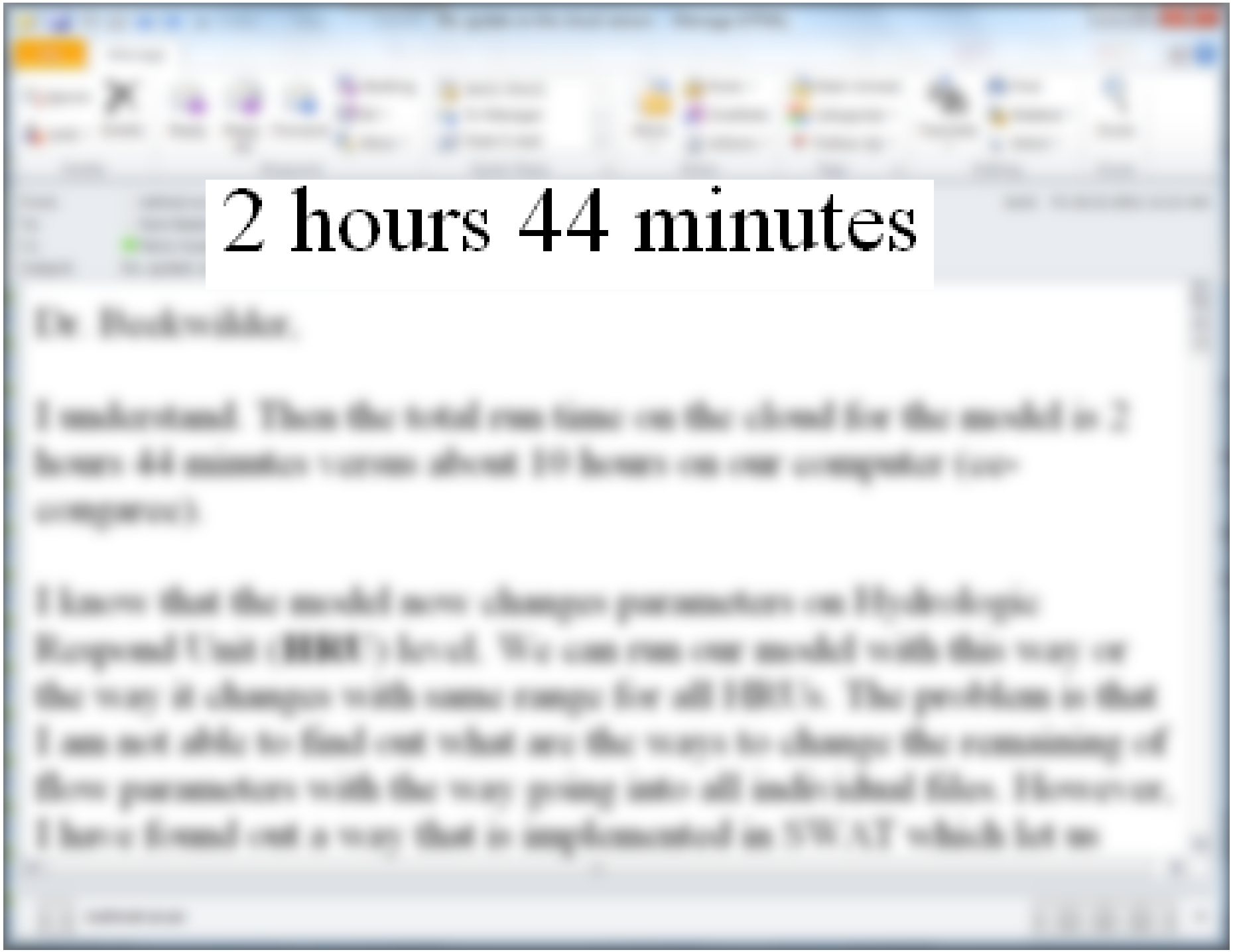
215	2	0.435030079124287	0.430177564846467	[Subbasin = 9, Monthly E = 0.430177564846467, Monthly R^2 = 0.492689608758142, Daily E = 0.435030079124287
215	3	0.501021560831151	0.445400065711808	[Subbasin = 9, Monthly E = 0.445400065711808, Monthly R^2 = 0.500649426165851, Daily E = 0.501021560831151
215	4	0.448744819957035	0.440016242695082	[Subbasin = 9, Monthly E = 0.440016242695082, Monthly R^2 = 0.496065138442328, Daily E = 0.448744819957035
215	5	0.51956086430255	0.43099698157476	[Subbasin = 9, Monthly E = 0.43099698157476, Monthly R^2 = 0.503963742286991, Daily E = 0.51956086430255, D
215	6	0.514446933166626	0.420894260411255	[Subbasin = 9, Monthly E = 0.420894260411255, Monthly R^2 = 0.502975755573573, Daily E = 0.514446933166626
215	7	0.452667041875028	0.45123090796741	[Subbasin = 9, Monthly E = 0.45123090796741, Monthly R^2 = 0.503218946219286, Daily E = 0.452667041875028,
215	8	0.515377393104625	0.415546753302534	[Subbasin = 9, Monthly E = 0.415546753302534, Monthly R^2 = 0.500532711453686, Daily E = 0.515377393104625
215	9	0.518694240600354	0.426704982246484	[Subbasin = 9, Monthly E = 0.426704982246484, Monthly R^2 = 0.500508918265719, Daily E = 0.518694240600354
215	10	0.493568916566423	0.456231549622343	[Subbasin = 9, Monthly E = 0.456231549622343, Monthly R^2 = 0.504628920854873, Daily E = 0.493568916566423
215	11	0.416955966312226	0.424203622164639	[Subbasin = 9, Monthly E = 0.424203622164639, Monthly R^2 = 0.492996863333701, Daily E = 0.416955966312226
215	12	0.445690509060064	0.449105269715507	[Subbasin = 9, Monthly E = 0.449105269715507, Monthly R^2 = 0.500259193622934, Daily E = 0.445690509060064
215	13	0.49355397331126	0.447015525582635	[Subbasin = 9, Monthly E = 0.447015525582635, Monthly R^2 = 0.500406035407888, Daily E = 0.49355397331126,
215	14	0.50128257724122	0.422206967197406	[Subbasin = 9, Monthly E = 0.422206967197406, Monthly R^2 = 0.4969032734016, Daily E = 0.50128257724122, Da
215	15	0.508337718856126	0.431533626688847	[Subbasin = 9, Monthly E = 0.431533626688847, Monthly R^2 = 0.505526188610535, Daily E = 0.508337718856126
215	16	0.471129147945864	0.442785011019014	[Subbasin = 9, Monthly E = 0.442785011019014, Monthly R^2 = 0.497083230851034, Daily E = 0.471129147945864
215	17	0.496680554462471	0.443531708959966	[Subbasin = 9, Monthly E = 0.443531708959966, Monthly R^2 = 0.499525215170893, Daily E = 0.496680554462471
215	18	0.52094989783067	0.420503562403376	[Subbasin = 9, Monthly E = 0.420503562403376, Monthly R^2 = 0.507040772193582, Daily E = 0.52094989783067,
215	19	0.512845721168434	0.441613896012705	[Subbasin = 9, Monthly E = 0.441613896012705, Monthly R^2 = 0.503041894175349, Daily E = 0.512845721168434
215	20	0.513870788314959	0.405570792007069	[Subbasin = 9, Monthly E = 0.405570792007069, Monthly R^2 = 0.496075647095762, Daily E = 0.513870788314959
215	21	0.46108884434218	0.434403512317391	[Subbasin = 9, Monthly E = 0.434403512317391, Monthly R^2 = 0.493896842020705, Daily E = 0.46108884434218,

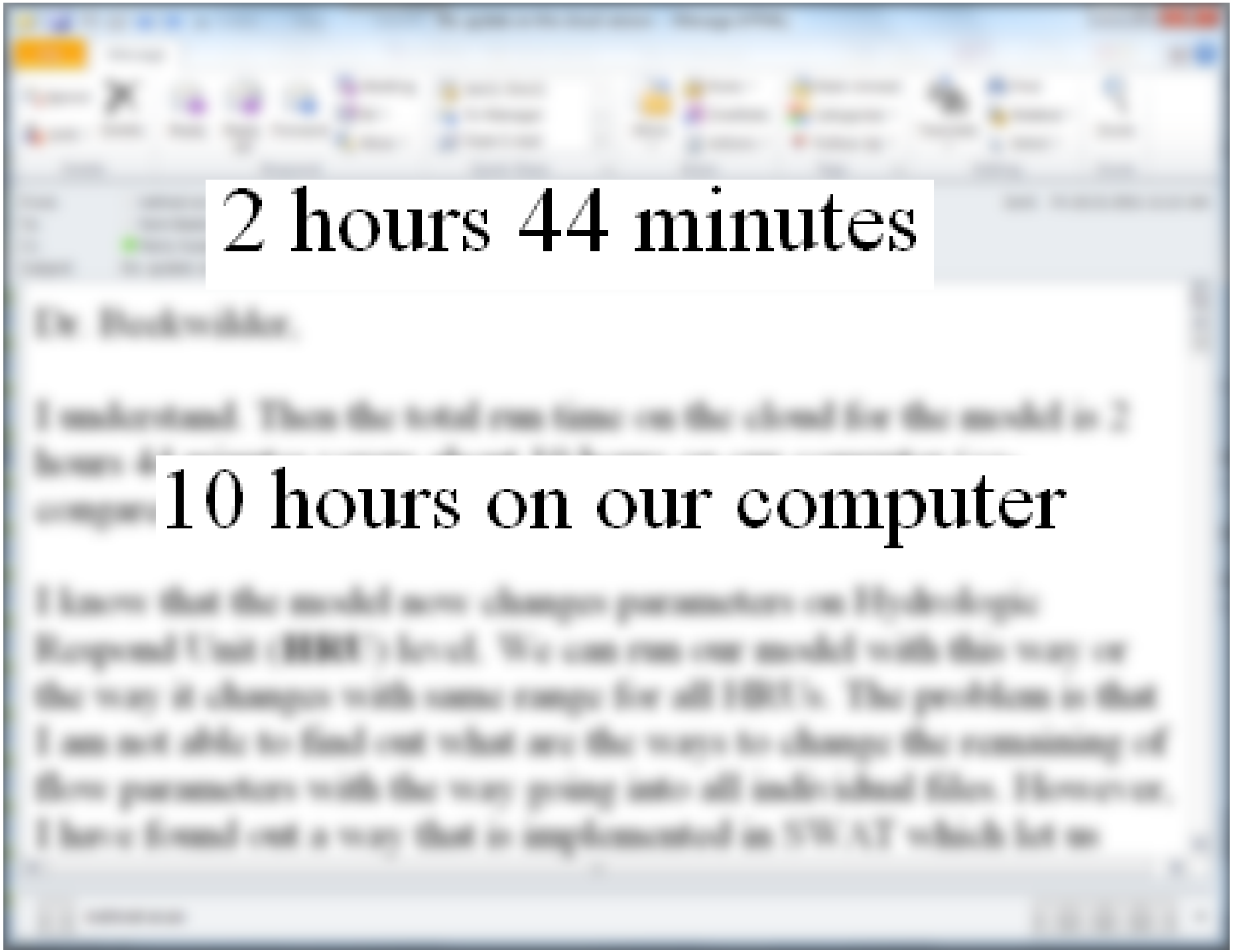

Re: update on the cloud version - Message (HTML)
File
Message
Ignore
Junk
Delete
Reply
Reply All
Forward
Meeting
IM
More
Jan11-Dec11
Team E-mail
Reply & Delete
To Manager
Done
Create New
Move
Rules
OneNote
Actions
Mark Unread
Categorize
Follow Up
Translate
Find
Related
Select
Zoom
Delete
Respond
Quick Steps
Move
Tags
Editing
Zoom
From: mehmet ercan <mehmetbercan@gmail.com>
Sent: Mon 10/17/2011 12:22 PM
To: GOODALL, JONATHAN L
Cc: Norm Beekwilder; Marty Humphrey
Subject: Re: update on the cloud version
I have tested new CN2 parameter on the cloud. 1008 times SWAT run (60 days time step) took 1 hour 54 minutes on the cloud (job: 136) and about 700 SWAT run (60 days time step) took about 10 minutes for automatic calibration implemented in SWAT. Best E value was 0.86 for the cloud and 0.89 for the SWAT automatic calibration. I can't see best CN2 result in percentage on cloud. Best CN2 value was + 9.99 % for SWAT automatic calibration.
Mehmet.
On Fri, Oct 14, 2011 at 4:43 PM, GOODALL, JONATHAN L <GOODALL@cec.sc.edu> wrote:
mehmet ercan


1 hour 54 minutes on the cloud

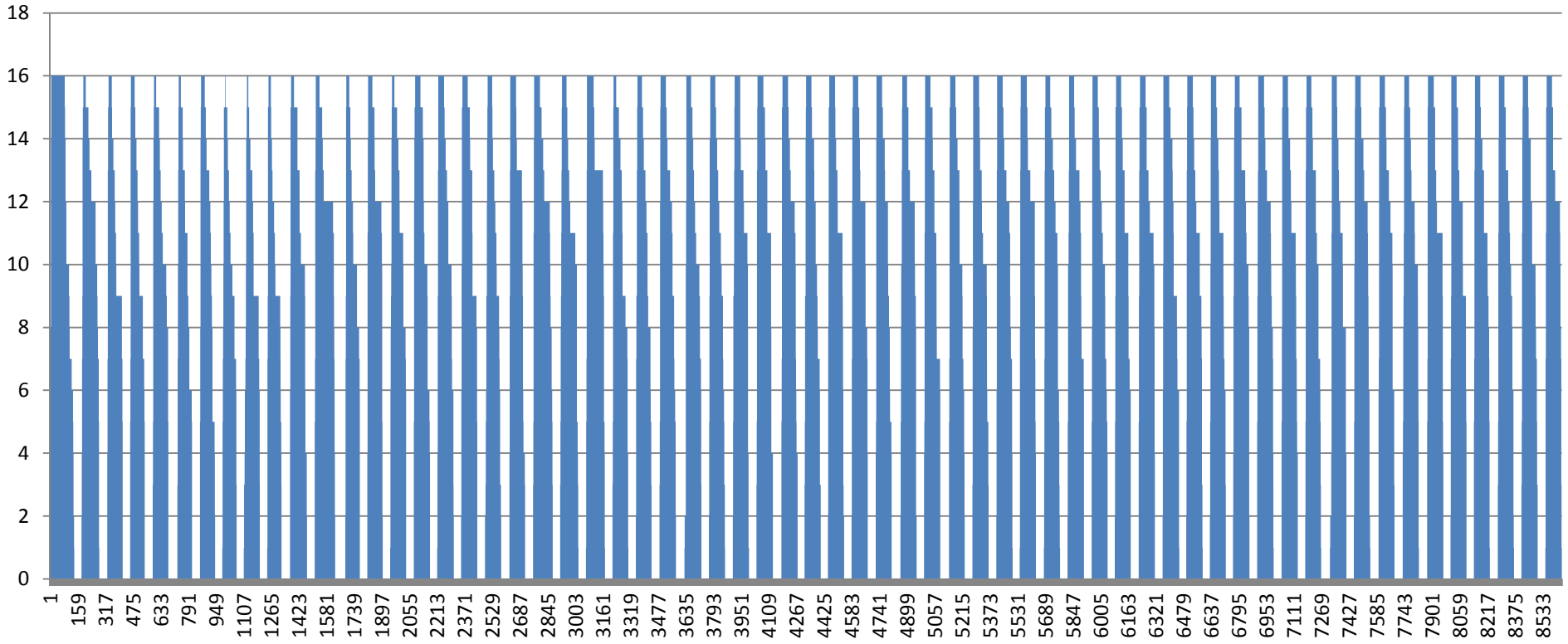

1 hour 54 minutes on the cloud
10 minutes for automatic calibration implemented in SWAT.


Re: update on the cloud version - Message (HTML)
File
Message
Ignore
Junk
Delete
Reply
Reply All
Forward
Meeting
IM
More
Jan11-Dec11
To Manager
Team E-mail
Move
Rules
OneNote
Actions
Mark Unread
Categorize
Follow Up
Translate
Find
Related
Select
Zoom
Delete
Respond
Quick Steps
Move
Tags
Editing
Zoom
From: mehmet ercan <mehmetbercan@gmail.com>
To: Norm Beekwilder
Cc: Marty Humphrey; GOODALL, JONATHAN L
Subject: Re: update on the cloud version
Sent: Fri 10/21/2011 11:13 AM
Dr. Beekwilder,
I understand. Then the total run time on the cloud for the model is 2 hours 44 minutes versus about 10 hours on our computer (ce-congaree).
I know that the model now changes parameters on Hydrologic Respond Unit (HRU) level. We can run our model with this way or the way it changes with same range for all HRUs. The problem is that I am not able to find out what are the ways to change the remaining of flow parameters with the way going into all individual files. However, I have found out a way that is implemented in SWAT which let us
mehmet ercan


2 hours 44 minutes


2 hours 44 minutes
10 hours on our computer

P-DDS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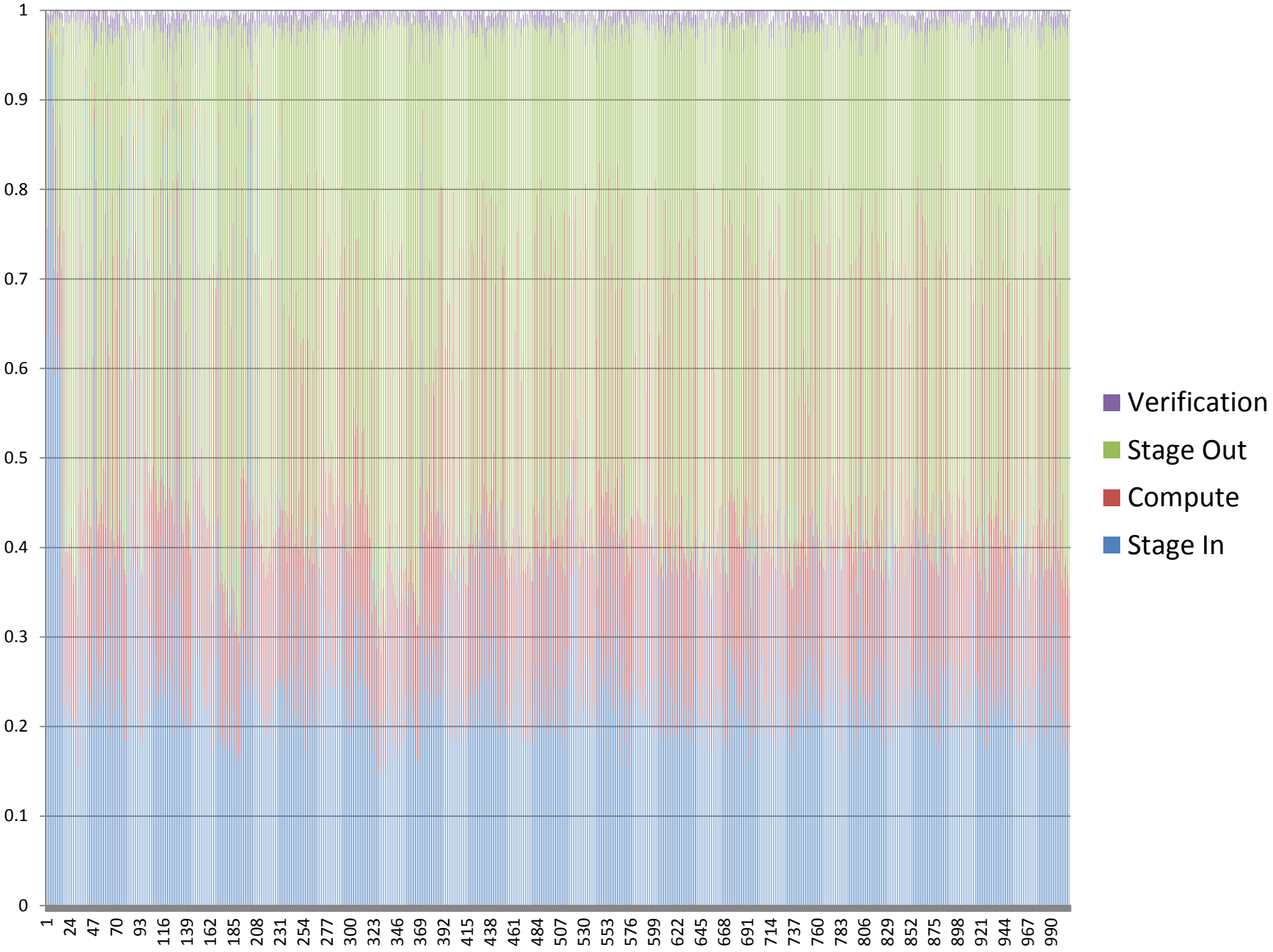
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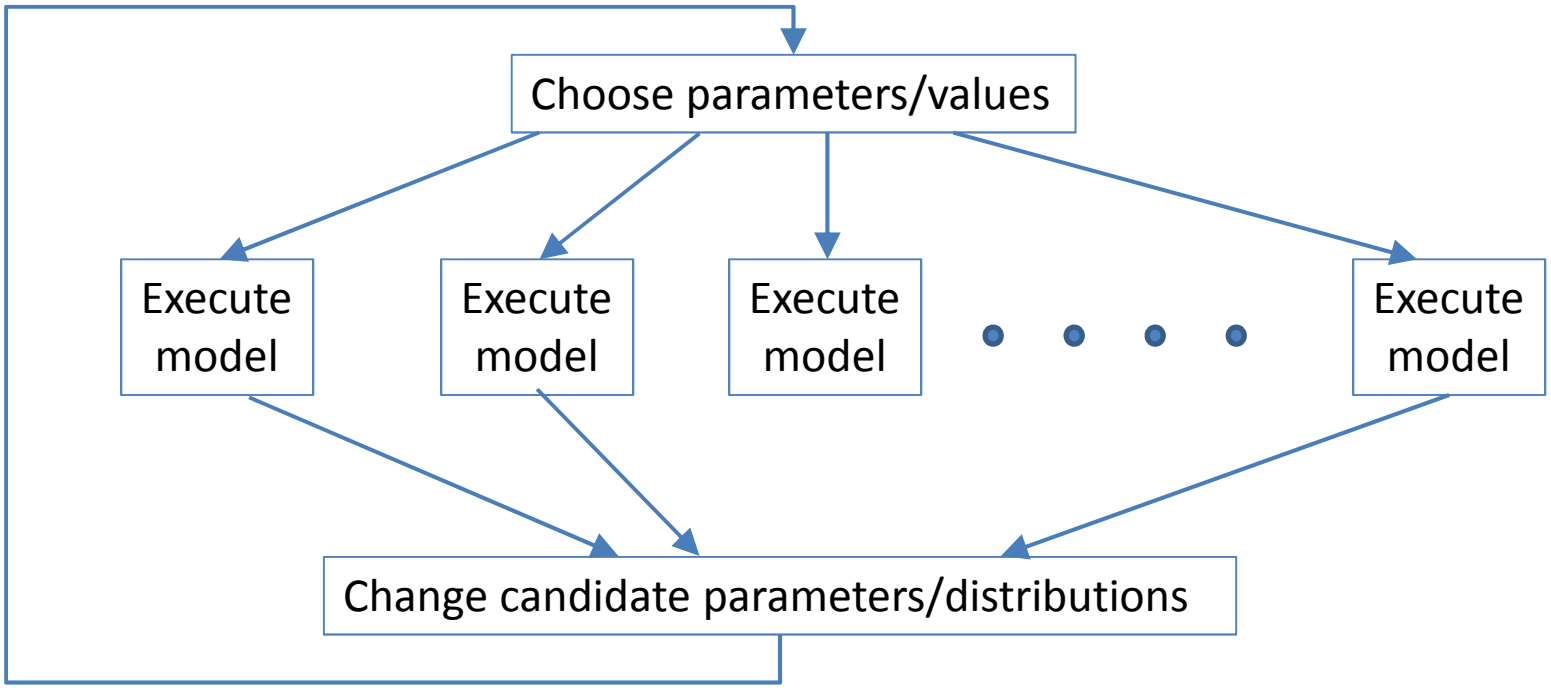
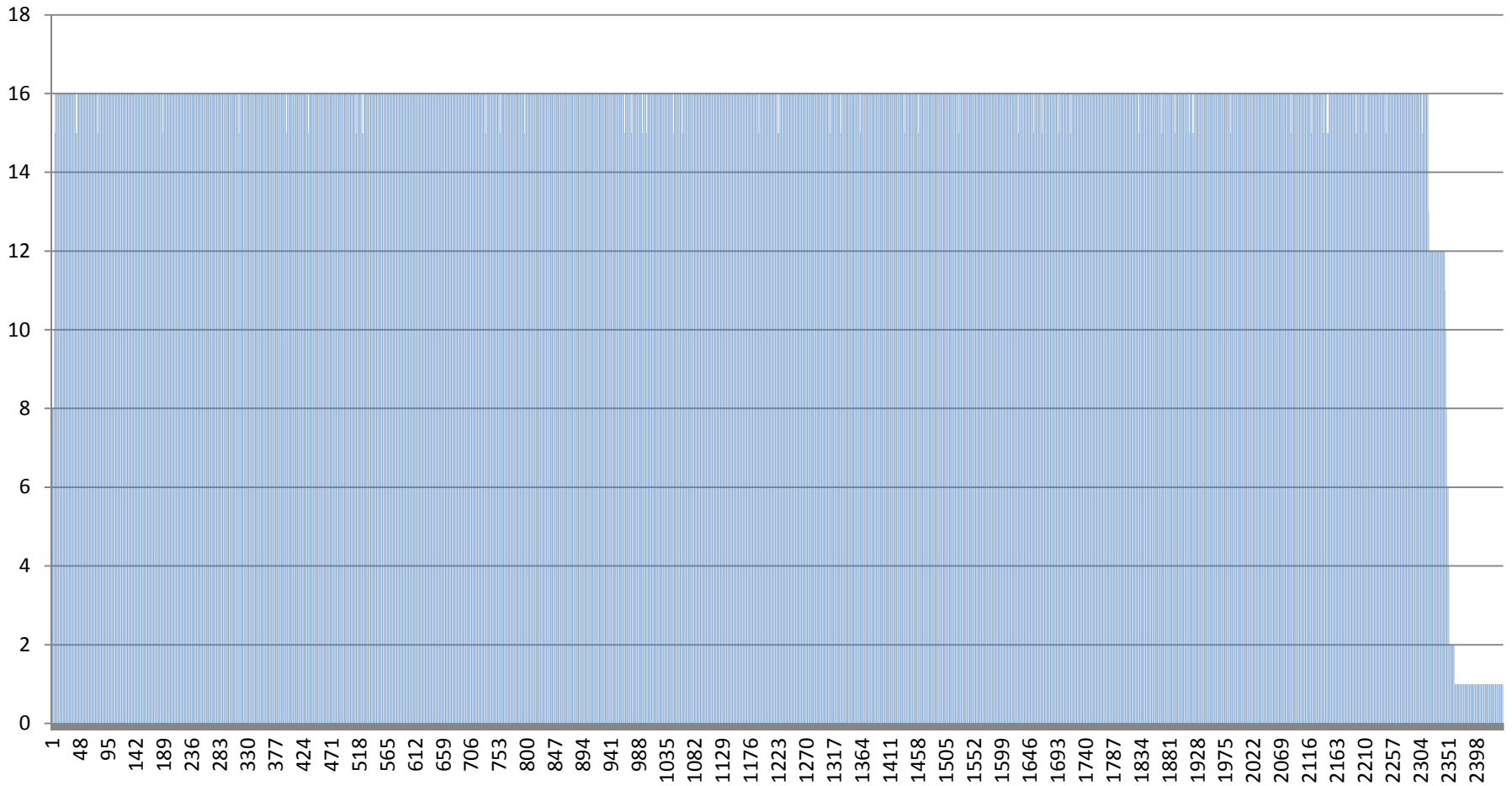
Verification
Stage Out
Compute
Stage In

NW-DDS


Choose parameters/values
Execute model
Execute model
Execute model
Execute model
Change candidate parameters/distributions

NW-DDS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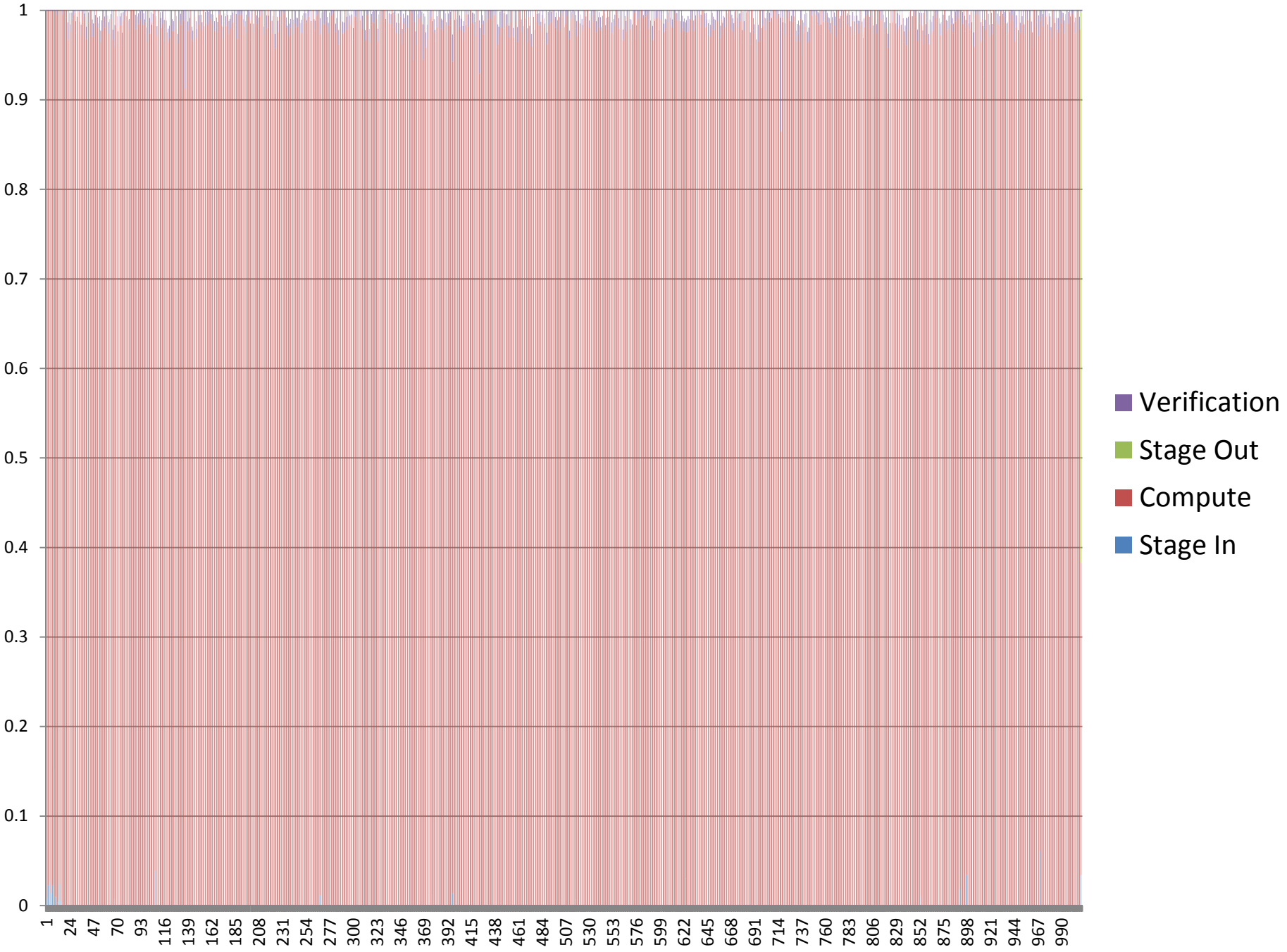
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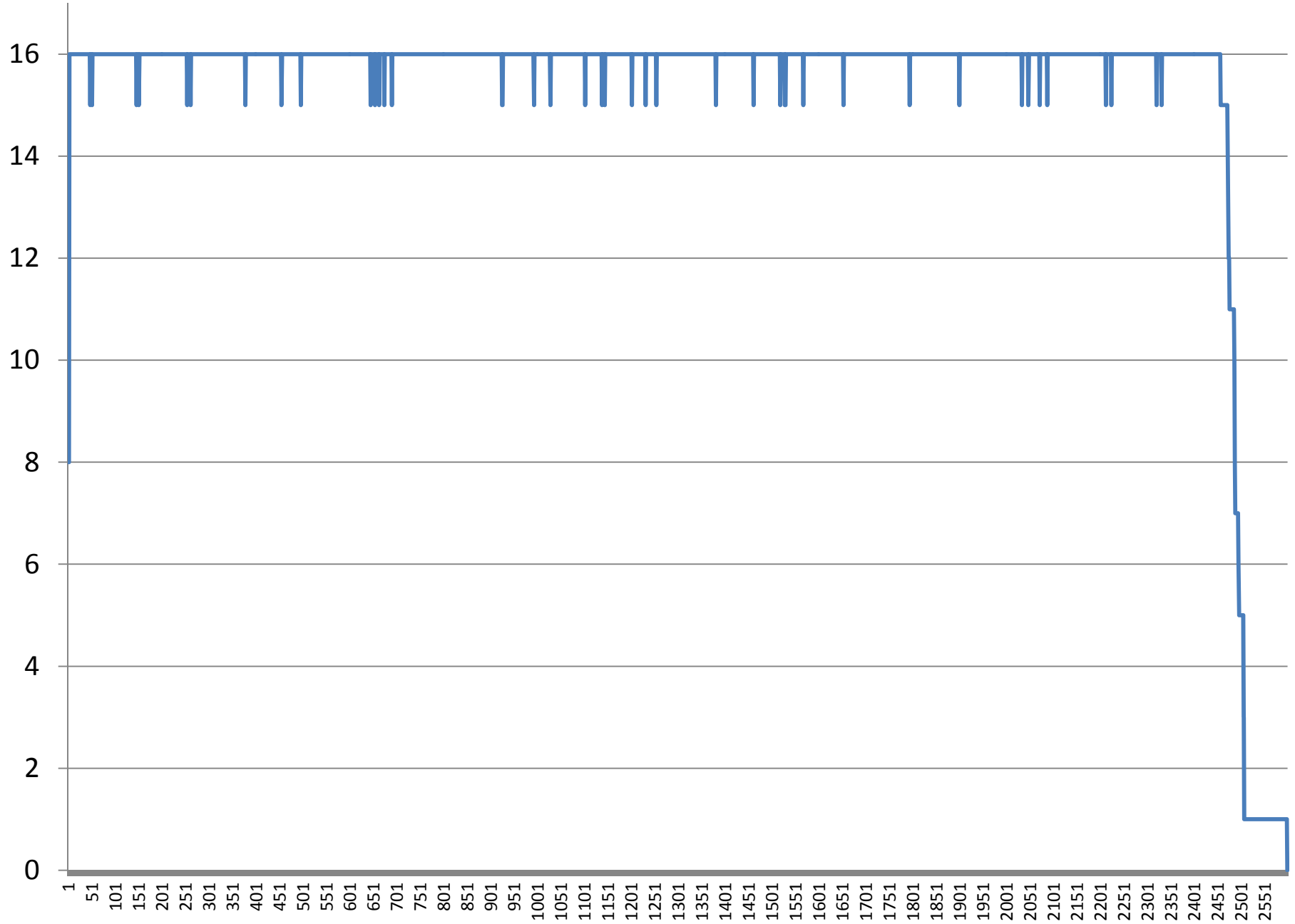
Verification
Stage Out
Compute
Stage In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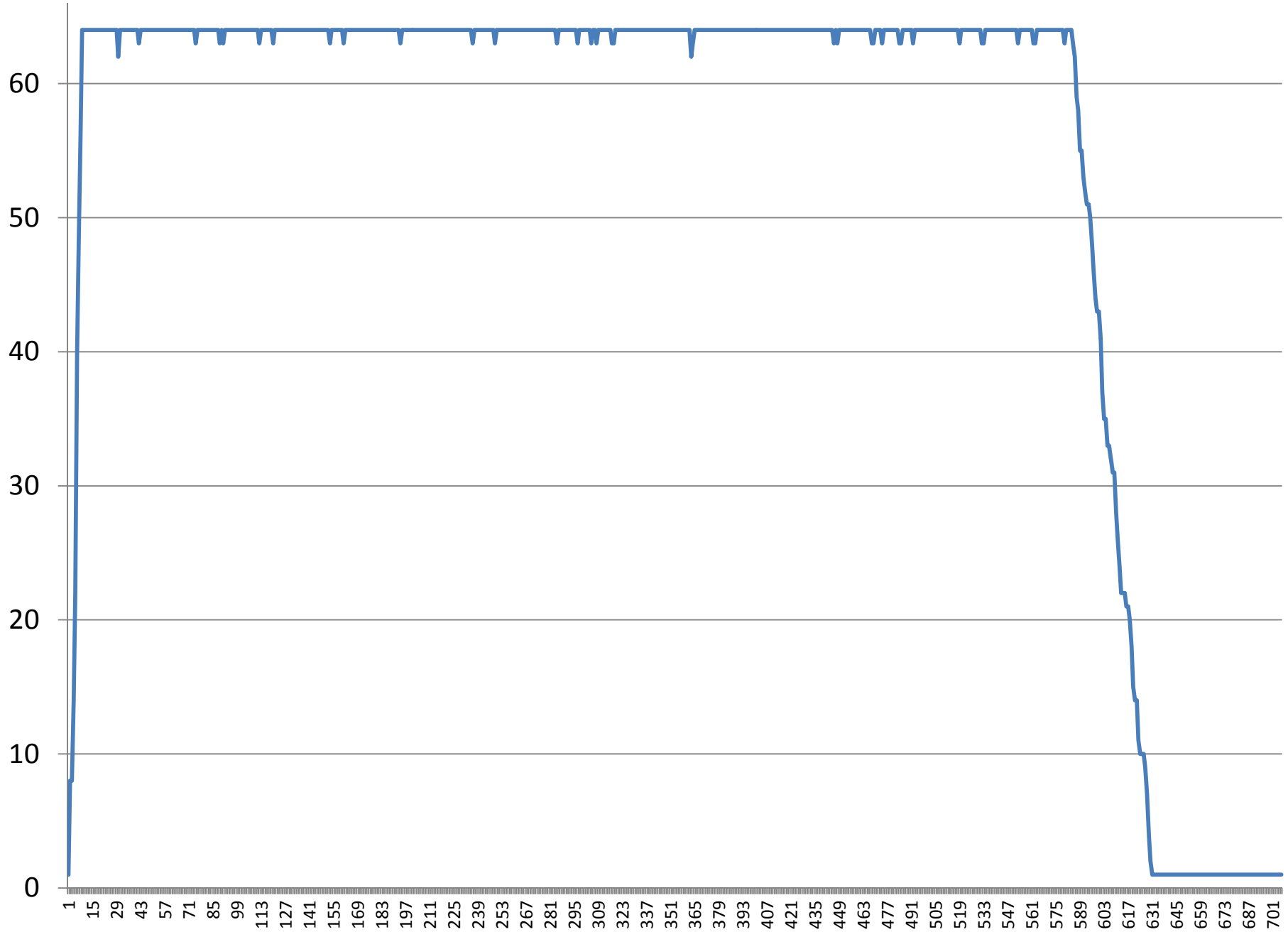
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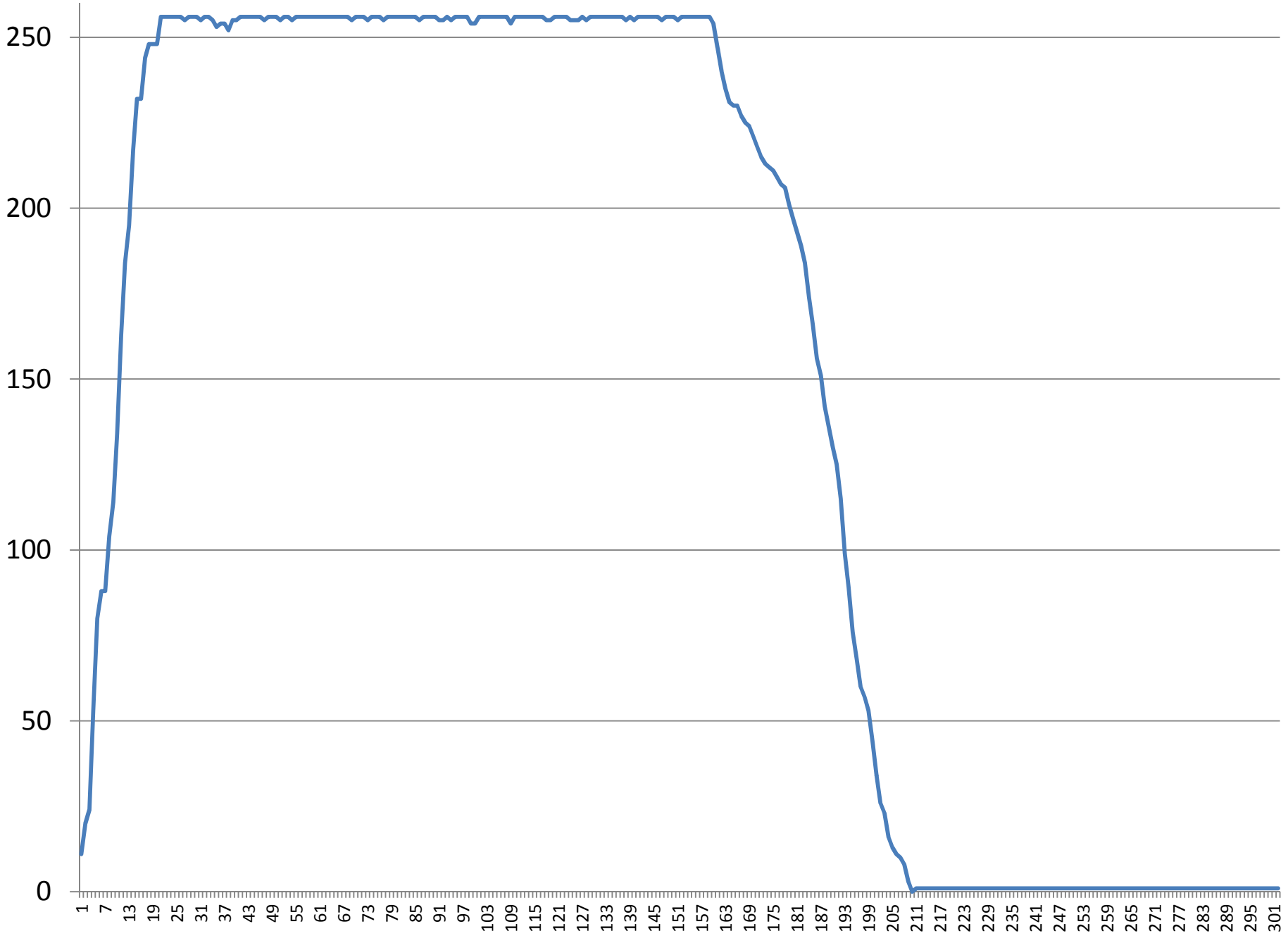
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Efficiency

	Duration	Speedup
Desktop, SWAT internal calibration (single threaded)	11.4 hours (41040 sec)	--
Windows Azure, Ex-large VM, 16 cores, NW-DDS	43.32 min (2599 sec)	15.78x
Windows Azure, Ex-large VM, 64 cores, NW-DDS	11.76 min (706 sec)	58.13x
Windows Azure, Ex-large VM, 256 cores, NW-DDS	5.03 min (302 sec)	135.89x

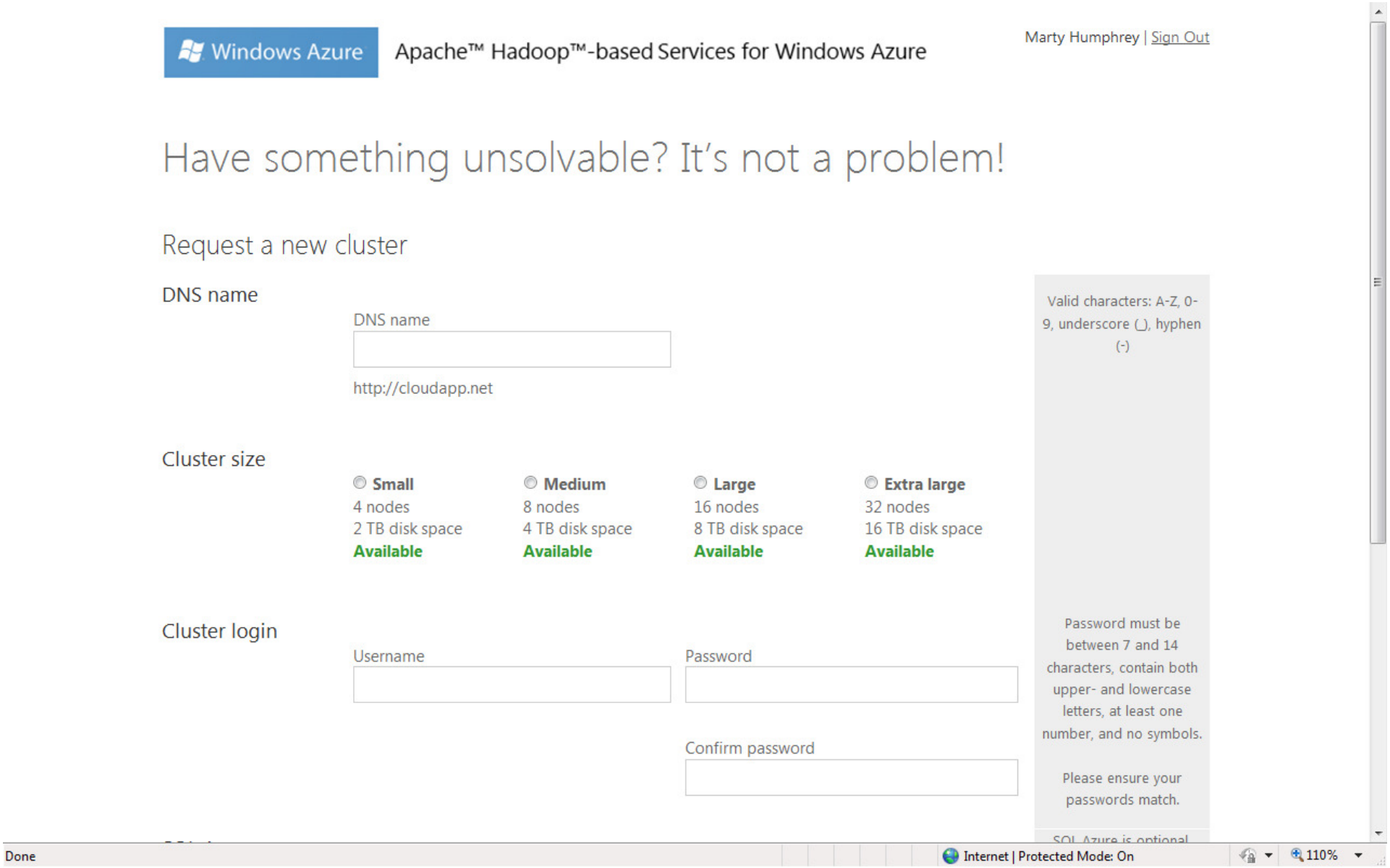
As number of cores increase, dominated by [a] stragglers, and [b] re-running best param set to get output files

Re-visiting the Issues (Cloud Futures, June 2011)

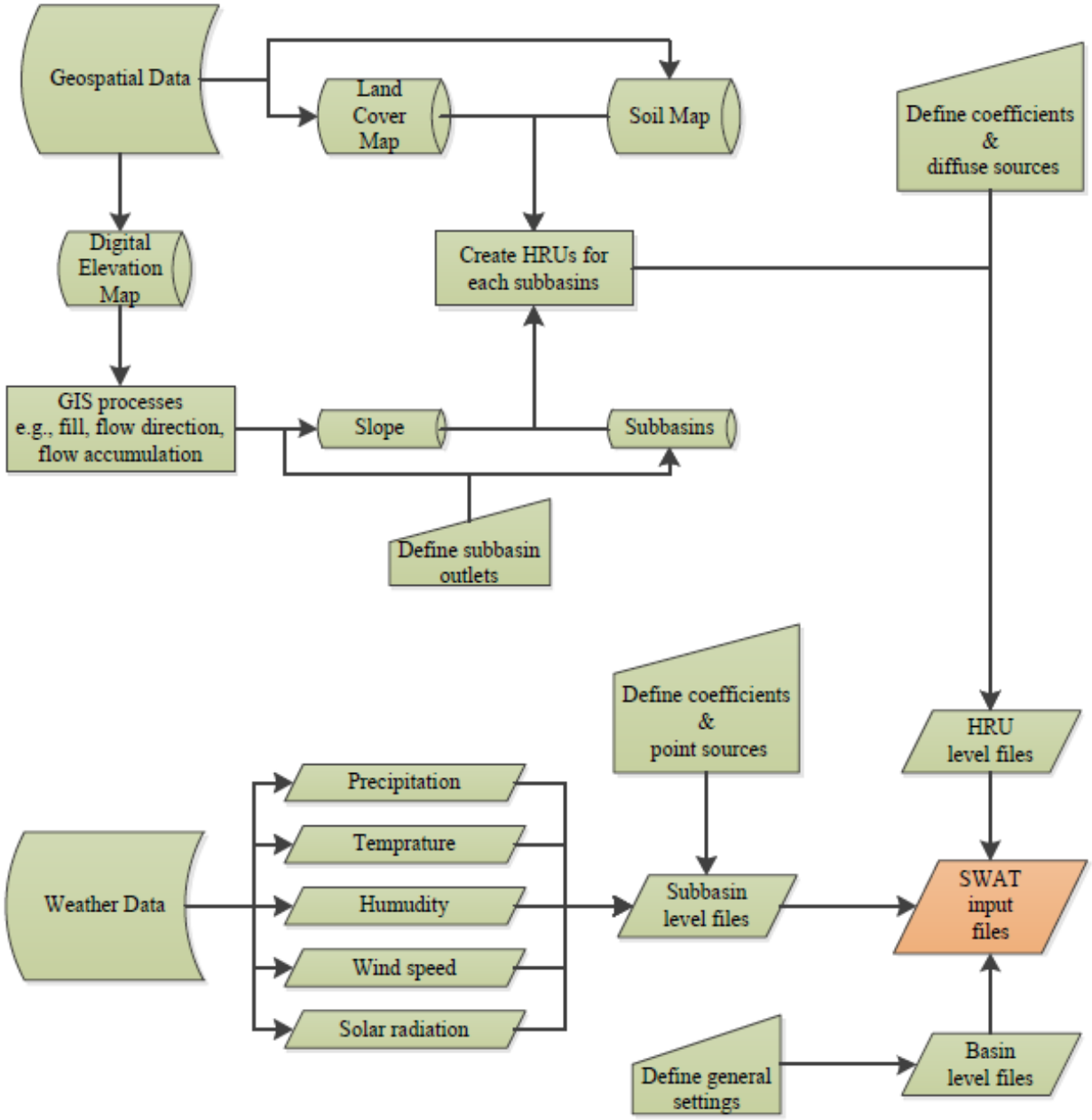
- Windows Azure only or cloudbursting?
  - *Only Windows Azure (with head node inside enterprise)*
- Data storage – where, how?
  - *Only Windows Azure, so [a] "where" is largely non-issue, and [b] "how" is as little as possible*
- Data sharing/reuse policy?
  - *Not as much as an issue as we would like*
- Task granularity / coding?
  - *Hmm… not exactly an issue (see next slide)*
- Task synchronization (e.g., MPI)?
  - *Removed in an uninteresting way*

Next steps: Calibration

- Additional watershed models (e.g., HSPF)
- Additional calibration algorithms
- Better control of search (e.g., stopping criteria)
  - Visual results presentation and visual steering
  - Trading off fast-vs.-more-exhaustive
- Better sharing / non-sharing
  - Insta-virtual-cluster a la HadoopOnAzure
- *How does insta-calibration change the watershed model design process? (continual calibration?)*


Windows Azure
Apache™ Hadoop™-based Services for Windows Azure
Marty Humphrey | Sign Out
Have something unsolvable? It's not a problem!
Request a new cluster
DNS name
DNS name
http://cloudapp.net
Valid characters: A-Z, 0-9, underscore (_), hyphen (-)
Cluster size
Small
4 nodes
2 TB disk space
Available
Medium
8 nodes
4 TB disk space
Available
Large
16 nodes
8 TB disk space
Available
Extra large
32 nodes
16 TB disk space
Available
Cluster login
Username
Password
Confirm password
Password must be between 7 and 14 characters, contain both upper- and lowercase letters, at least one number, and no symbols.
Please ensure your passwords match.
Done
Internet | Protected Mode: On
110%

Next steps: Data preparation



Observations on Windows Azure

- Does Windows Azure (more broadly: cloud computing) substantially change the challenges of collaboration between domains? No.
- What do we like?
  - Cloudbursting mechanism (head node, VPN).
  - Predictability is sufficient (and continues to improve).
- What would we like to see?
  - Faster boot time for VMs.
  - Non-round-up cost-model.
  - Faster speed of light.

Summary

- Goals: Watershed calibration, data prep, and large-scale modeling
- Good progress on watershed calibration, data prep next
- Basic issues of collaboration across domains will continue to dominate