04/22/2014

Phase 6 Watershed Model

Modeling Quarterly Meeting

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Outline of presentation

1. Expansion of simulation period to 2014

2. Incorporation of rSAS into Phase 6 WSM framework

3. WSM calibration with revised *(version II)* SPARROW based L2W, S2R ***variances*** to account for small scale processes

1. Expansion of simulation period to 2014

Expansion of simulation period to 2014

Data gathering / Data development

- Precipitation & meteorological forcing:
  - Cloud cover, Dew-point temperature, Potential evapotranspiration, Precipitation, Solar radiation, Temperature, and Wind speed
- Atmospheric deposition *(based on detrended datasets)*
- Streamflow observations for years 1985-2014 *by Yactayo & Hinson*
- Point sources *(using progress year datasets)*
- Water diversions *(using years 2002-2003 up to 2014)*
- Water quality monitoring *(1985-2011)*

1. Expansion of simulation period to 2014

1.1 Hydrology Calibration

1.2 Sediment Calibration

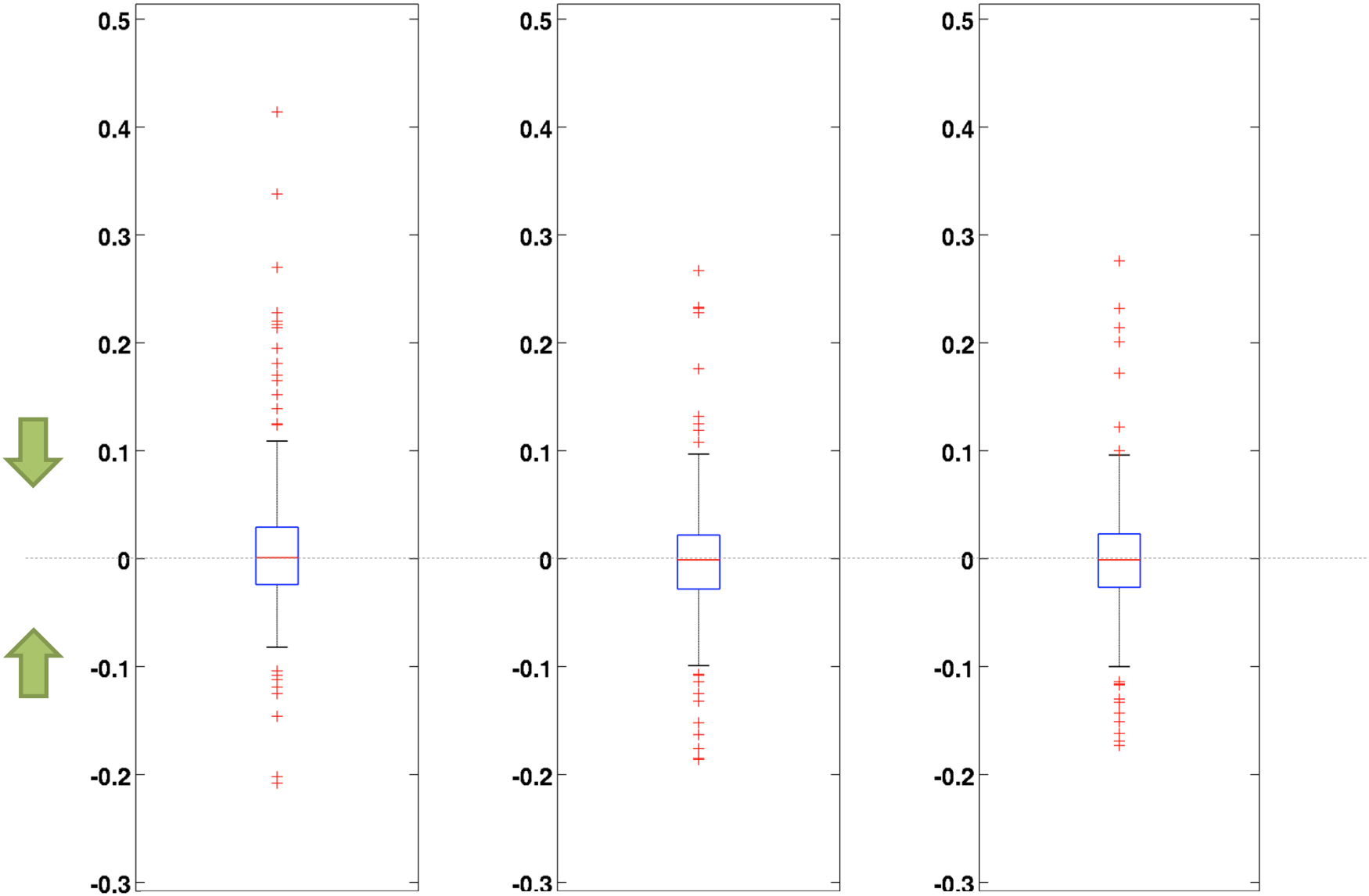
1.3 Nutrient Calibration

30-years of watershed hydrology

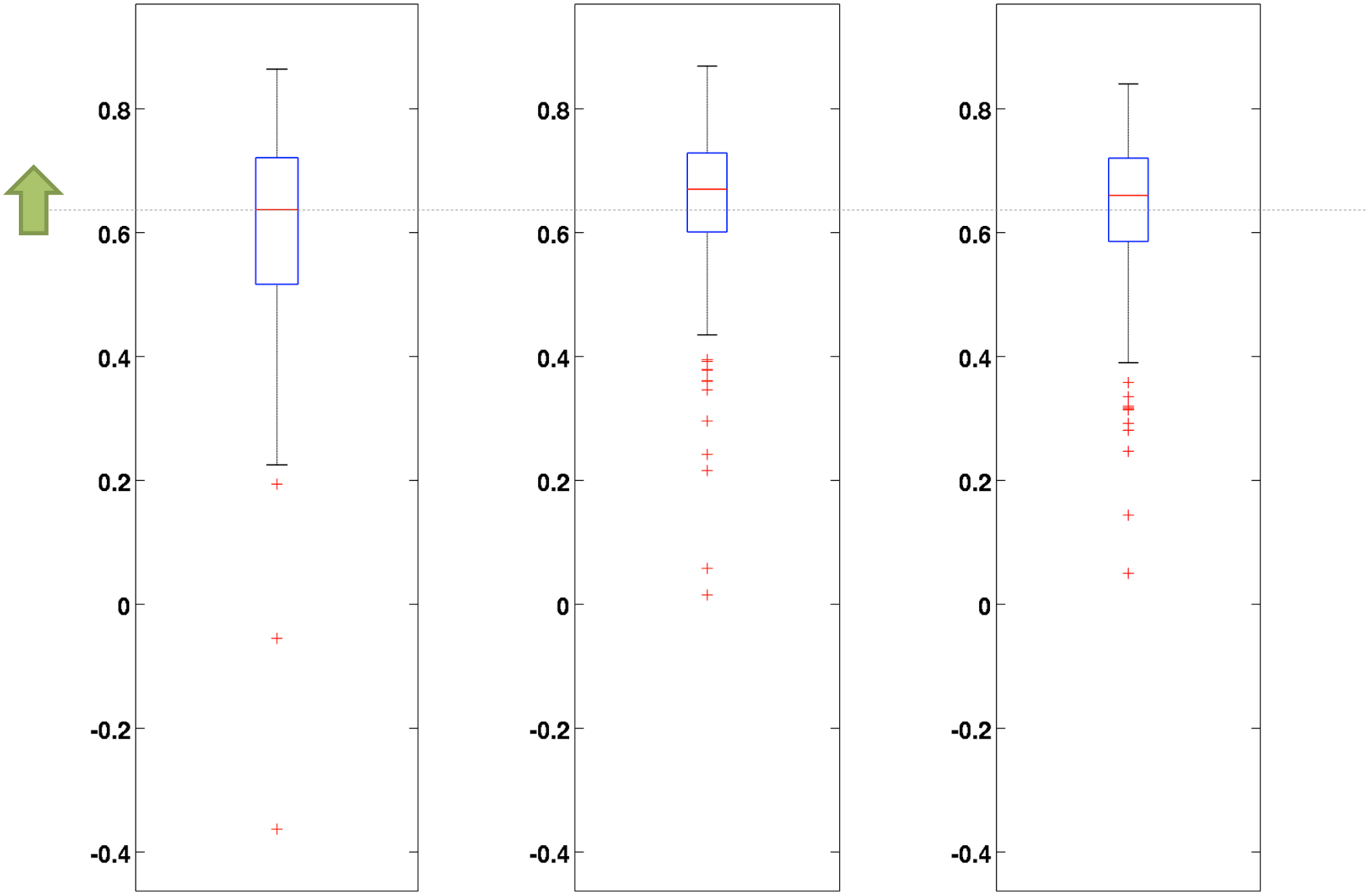
Phase 5.3.2 *[Phase 5]*	**Phase 6 (1985-2005)** *[Phase 6 Oct'14]*	**Phase 6 (1985-2014)** *[Phase 6 Apr'15]*
XYZ based forcing	NLDAS based forcing	NLDAS based forcing *
1985 - 2005	1985 - 2005	**1985 – 2014**
TSNOW = 32 °F	TSNOW = 35.6 °F	TSNOW = 35.6 °F
SNOWCF = 1.3	SNOWCF = 1.0	SNOWCF = 1.0

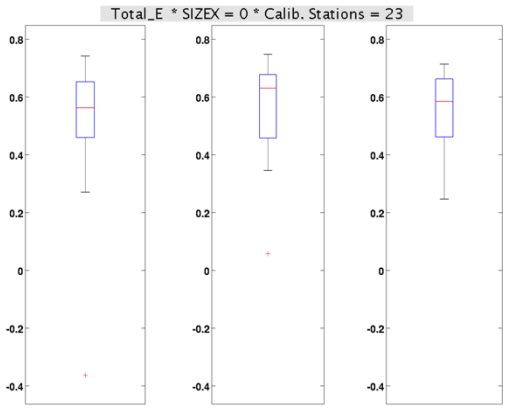
* data updates, and complete restructuring of data processing tools.

Model Bias, Number of Calibration Stations = 201



Nash-Sutcliffe Efficiency, Number of Calibration Stations = 201

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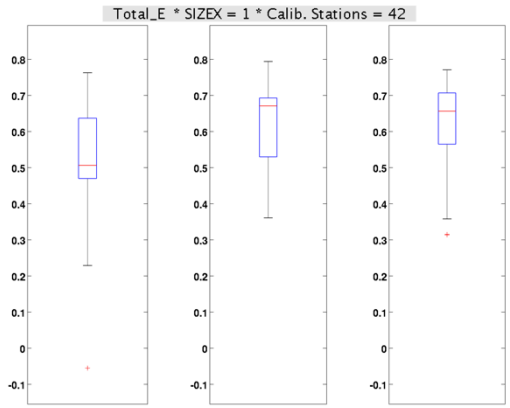
Phase 532
Phase 6 (1985-2005)
Phase 6 (1985-2014)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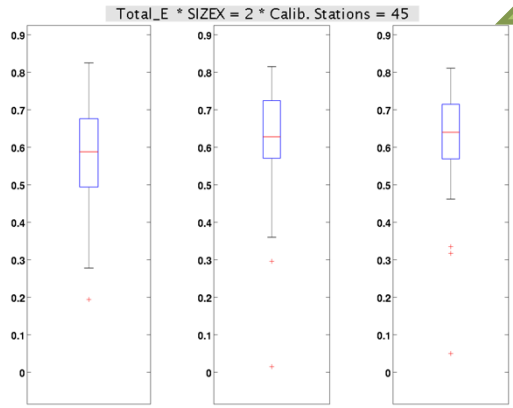
Phase 532
Phase 6 (1985-2005)
Phase 6 (1985-2014)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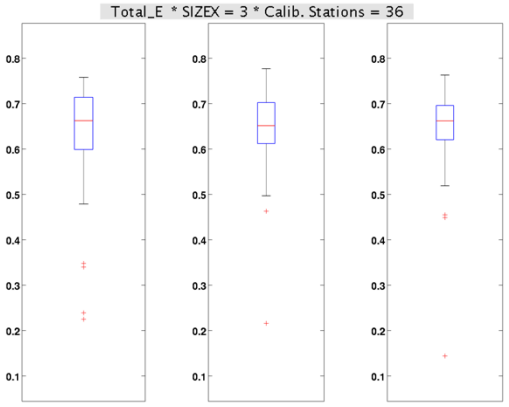
Phase 532
Phase 6 (1985-2005)
Phase 6 (1985-2014)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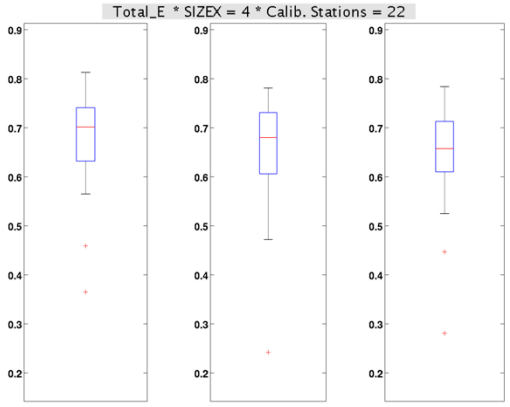
Phase 532
Phase 6 (1985-2005)
Phase 6 (1985-2014)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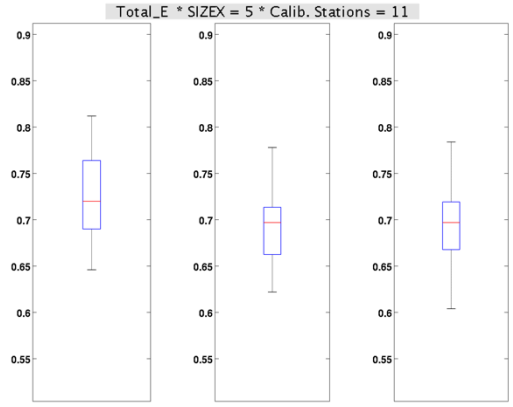
Phase 532
Phase 6 (1985-2005)
Phase 6 (1985-2014)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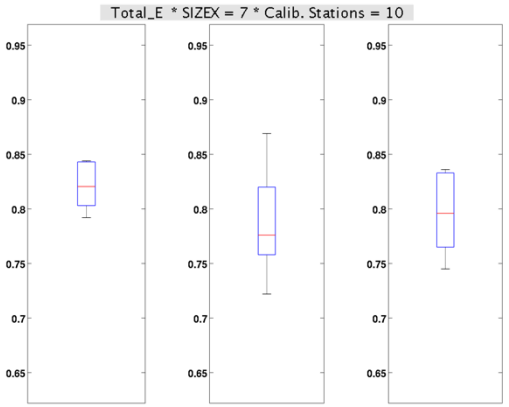
Phase 532
Phase 6 (1985-2005)
Phase 6 (1985-2014)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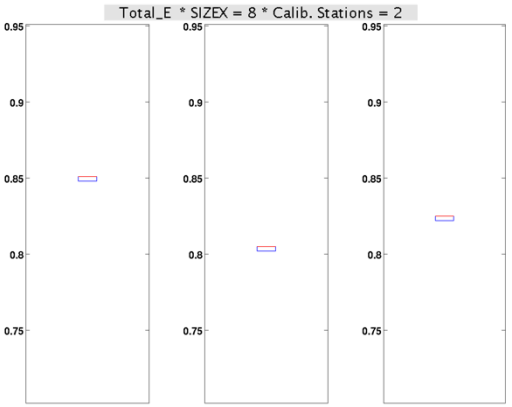
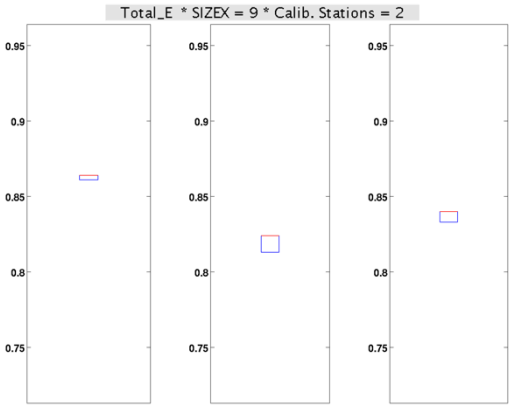
Phase 532
Phase 6 (1985-2005)
Phase 6 (1985-2014)


Total_E * SIZEX = 8 * Calib. Stations = 2
Phase 532
Phase 6 (1985-2005)
Phase 6 (1985-2014)


Total_E * SIZEX = 9 * Calib. Stations = 2
Phase 532
Phase 6 (1985-2005)
Phase 6 (1985-2014)

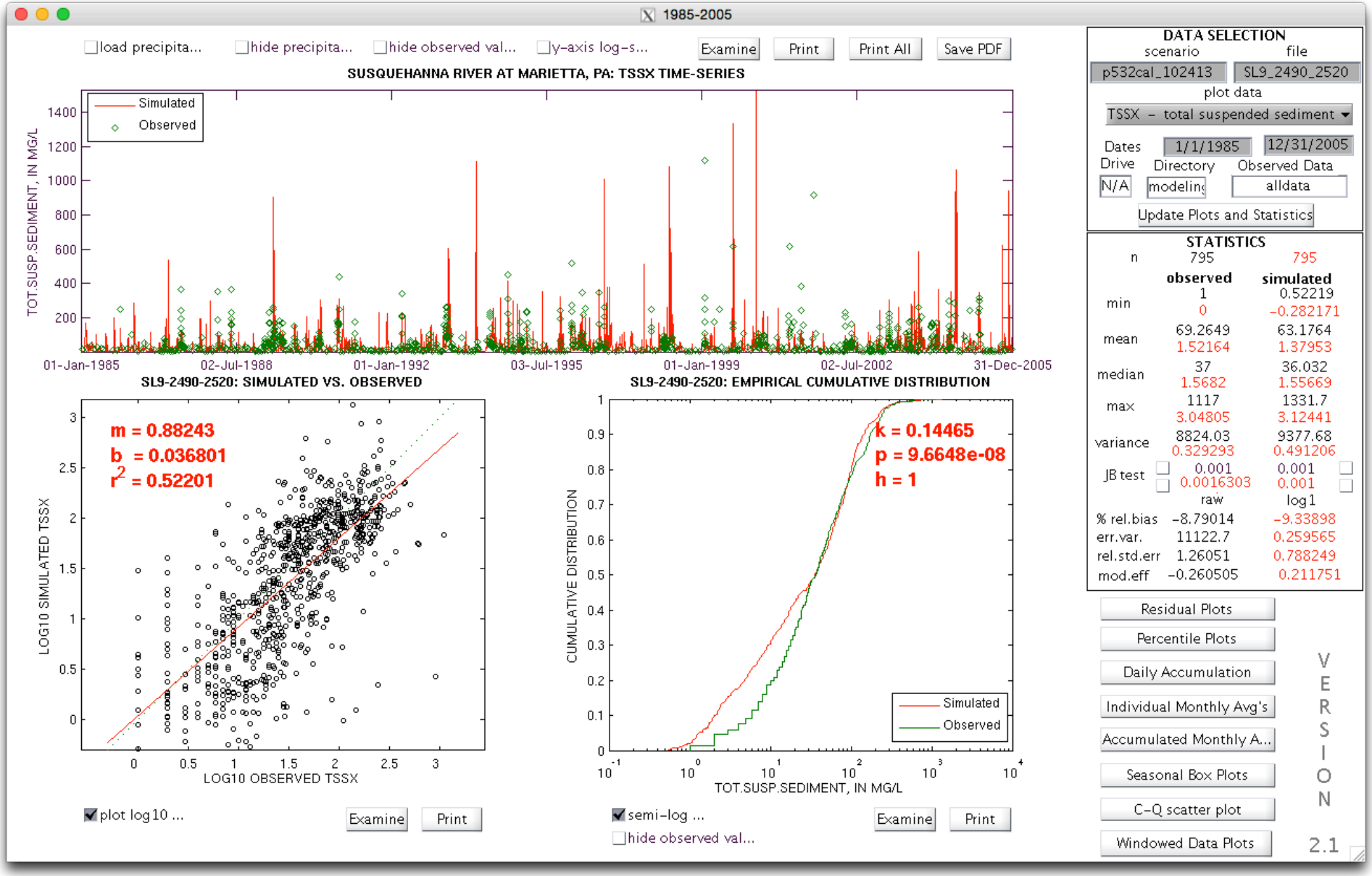
1. Expansion of simulation period to 2014

1.1 Hydrology Calibration

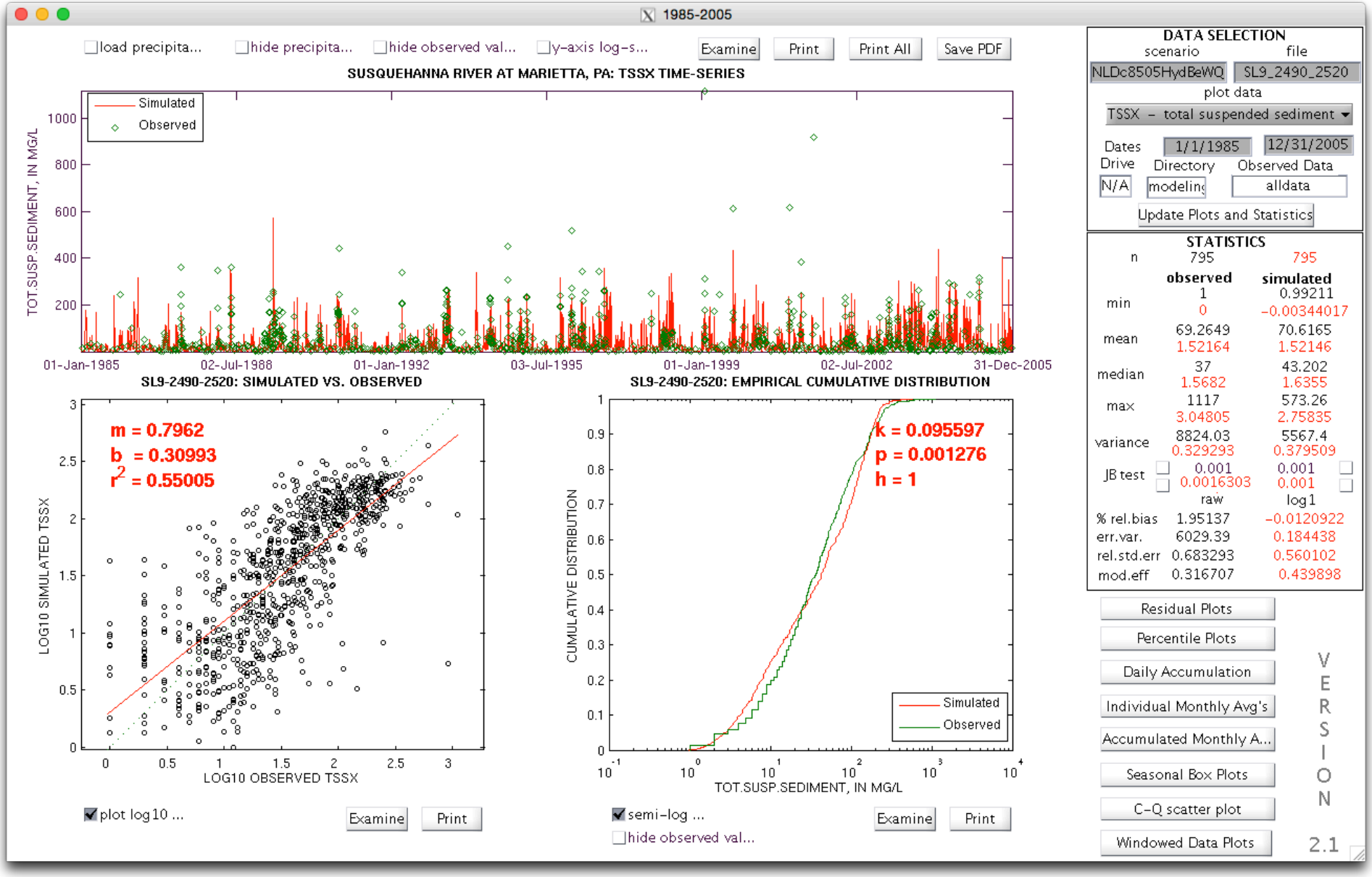
1.2 Sediment Calibration

1.3 Nutrient Calibration

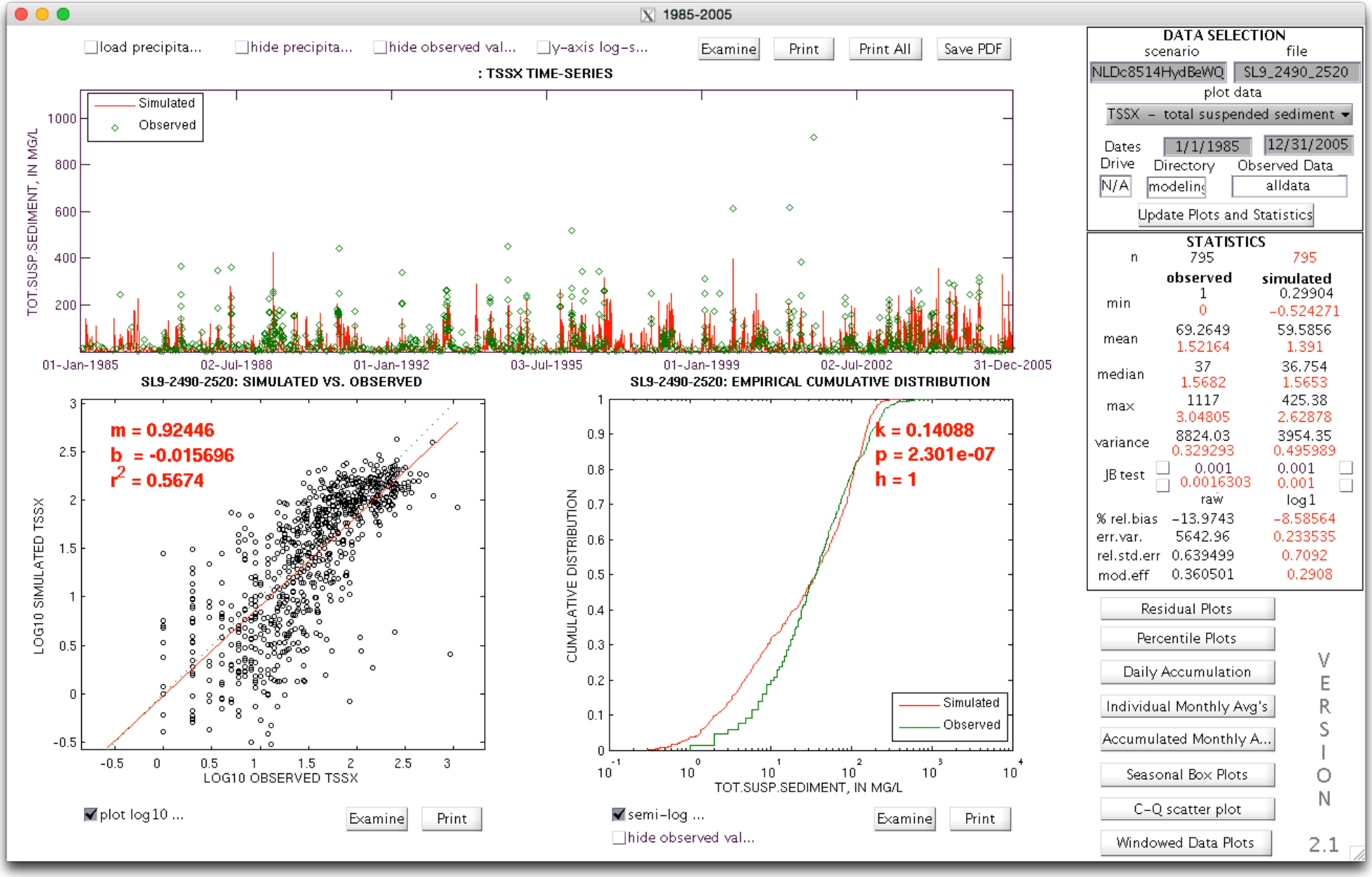
Phase 5, 1985-2005, TSS, Susquehanna at Marietta



Phase 6 Oct'14, 1985-2005, TSS, Susquehanna at Marietta



Phase 6 Apr'15, 1985-2005, TSS, Susquehanna at Marietta



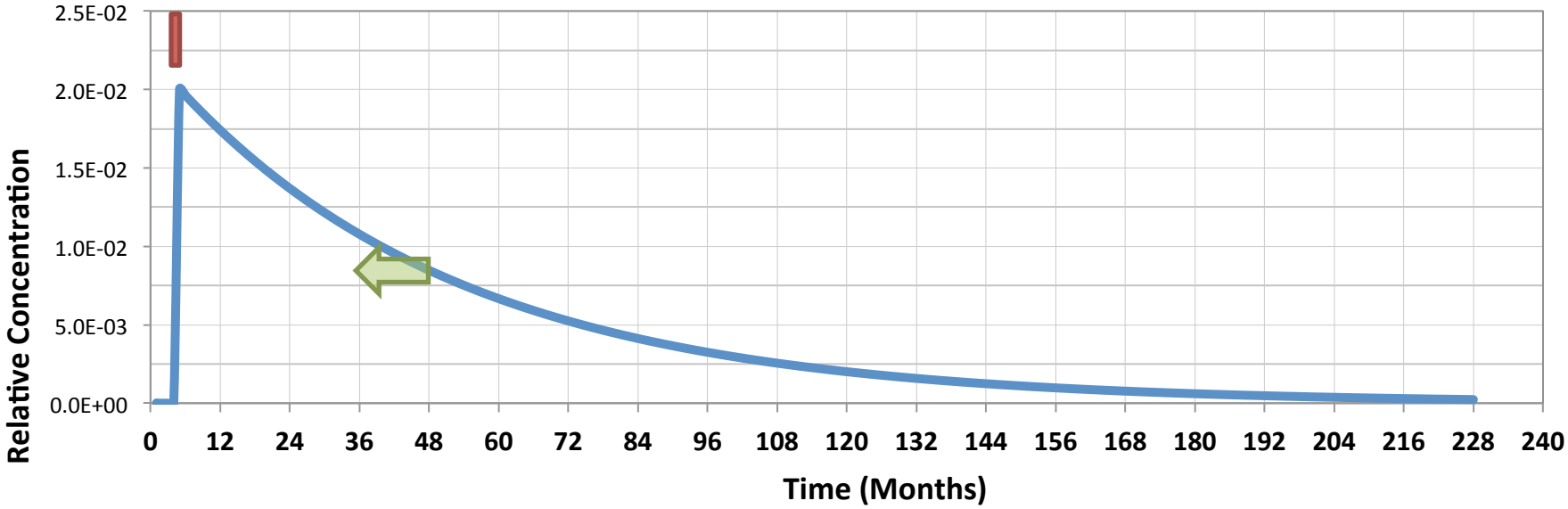
1. Expansion of simulation period to 2014

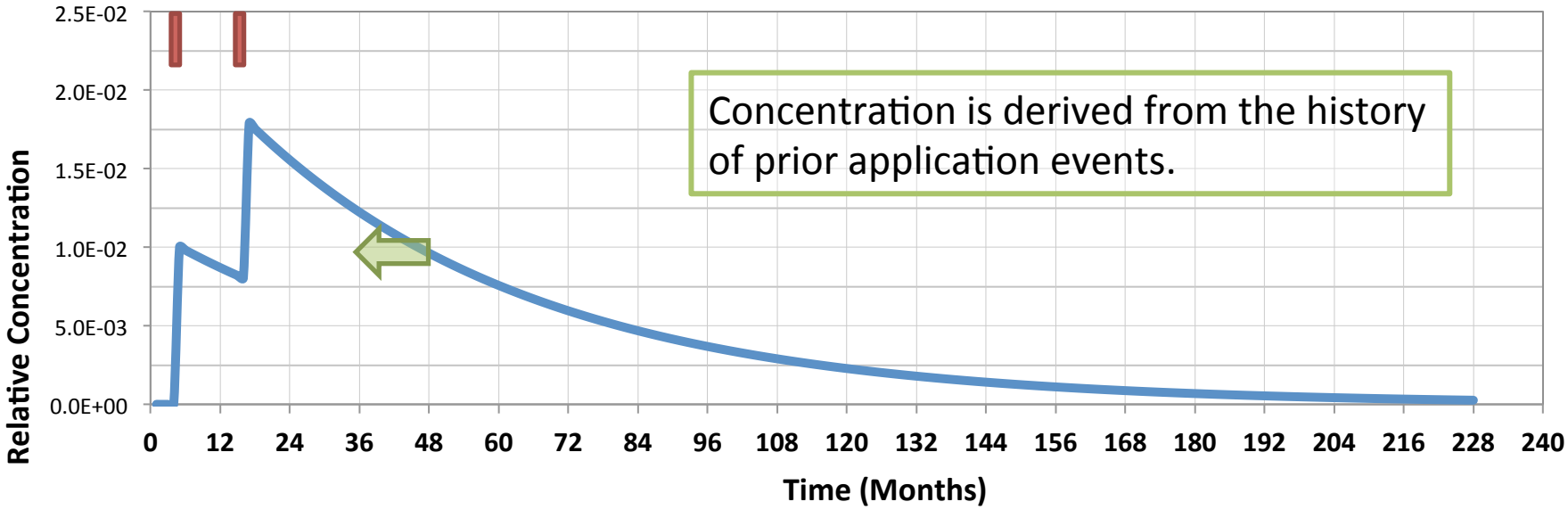
1.1 Hydrology Calibration

1.2 Sediment Calibration

1.3 Nutrient Calibration

Unit Nutrient Export Curve (UNEC)

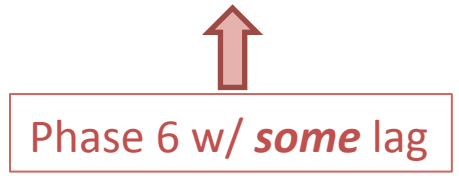


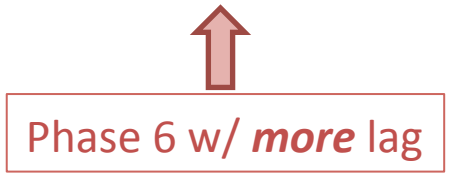


Mean residence time or Turn-over time

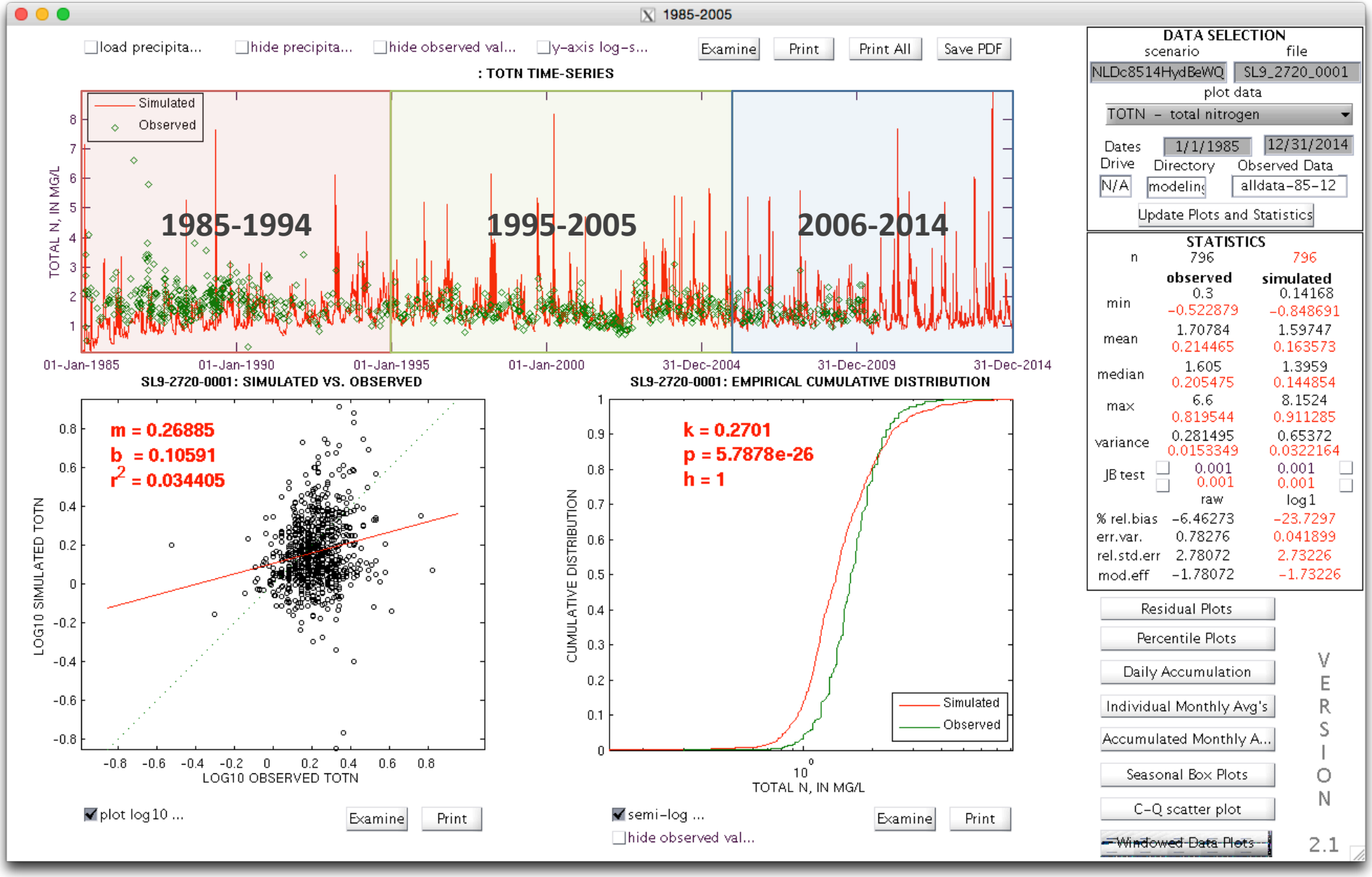
(time taken for 50% of mass to exit the system)

Nutrient Transport	Phase 5	Phase 6, Oct'2014	Phase 6, Apr'2015
Surface flow	AGCHEM/PQUAL	UNEC - *3 months*	UNEC - *3 months*
Sediment flux	AGCHEM/PQUAL	UNEC - *4 months*	UNEC - *4 months*
Inter-flow	AGCHEM/PQUAL	UNEC - *8 months*	UNEC - *15 months*
Groundwater flow	AGCHEM/PQUAL	UNEC - *12 months*	UNEC - *51 months*



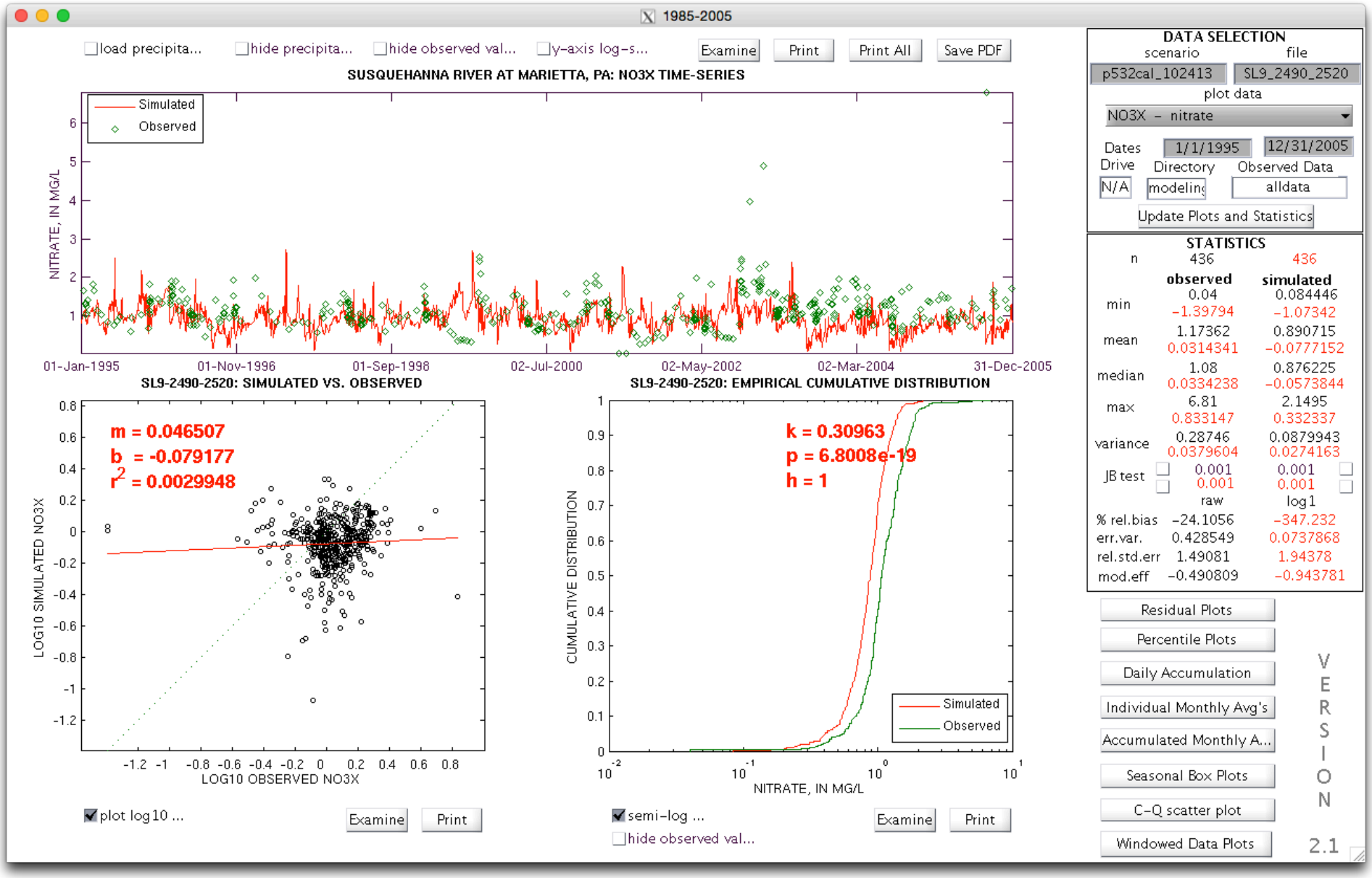


1985-2014, Nitrogen, Susquehanna at Conowingo

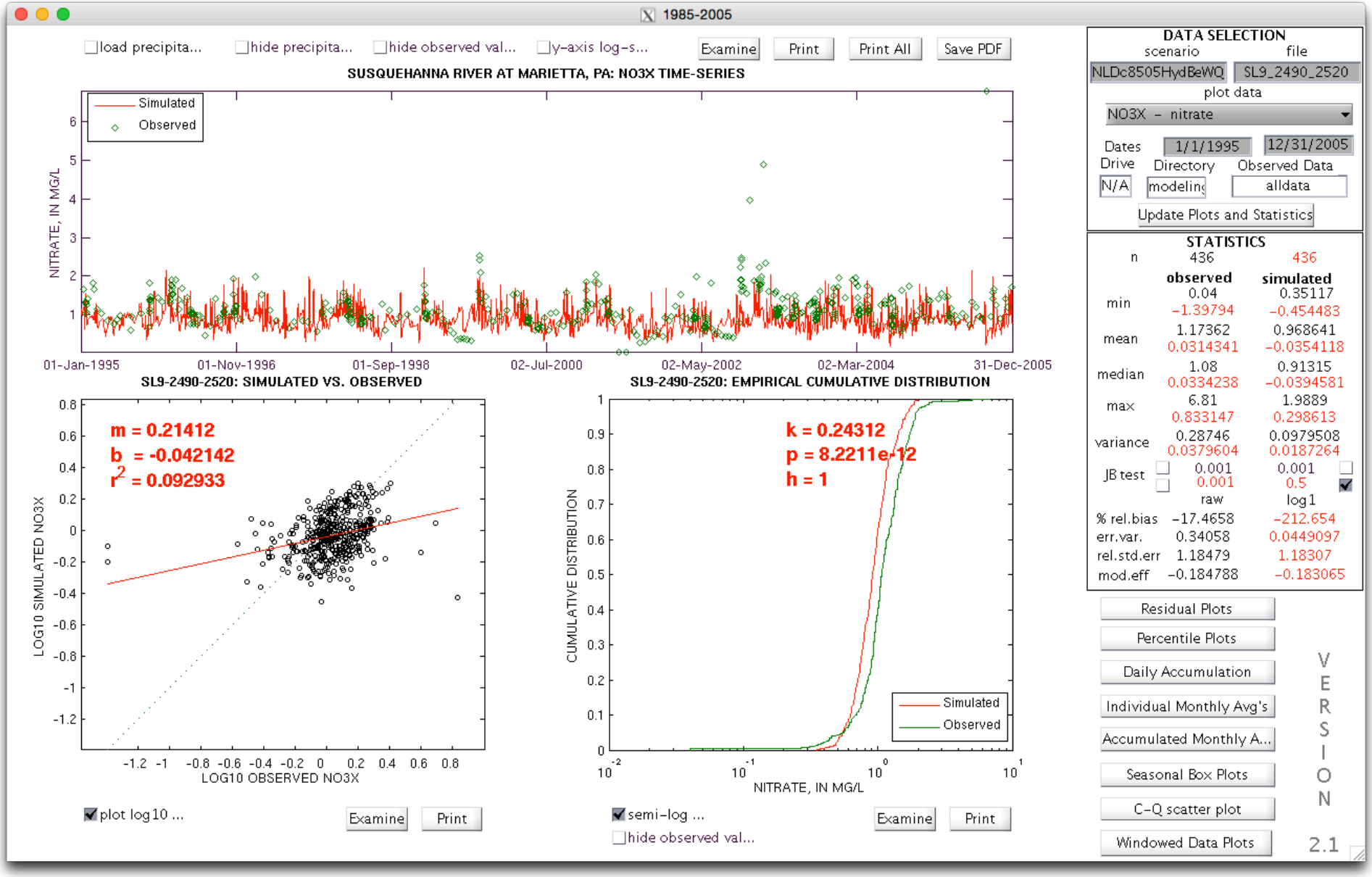


Susquehanna River at Marietta, PA

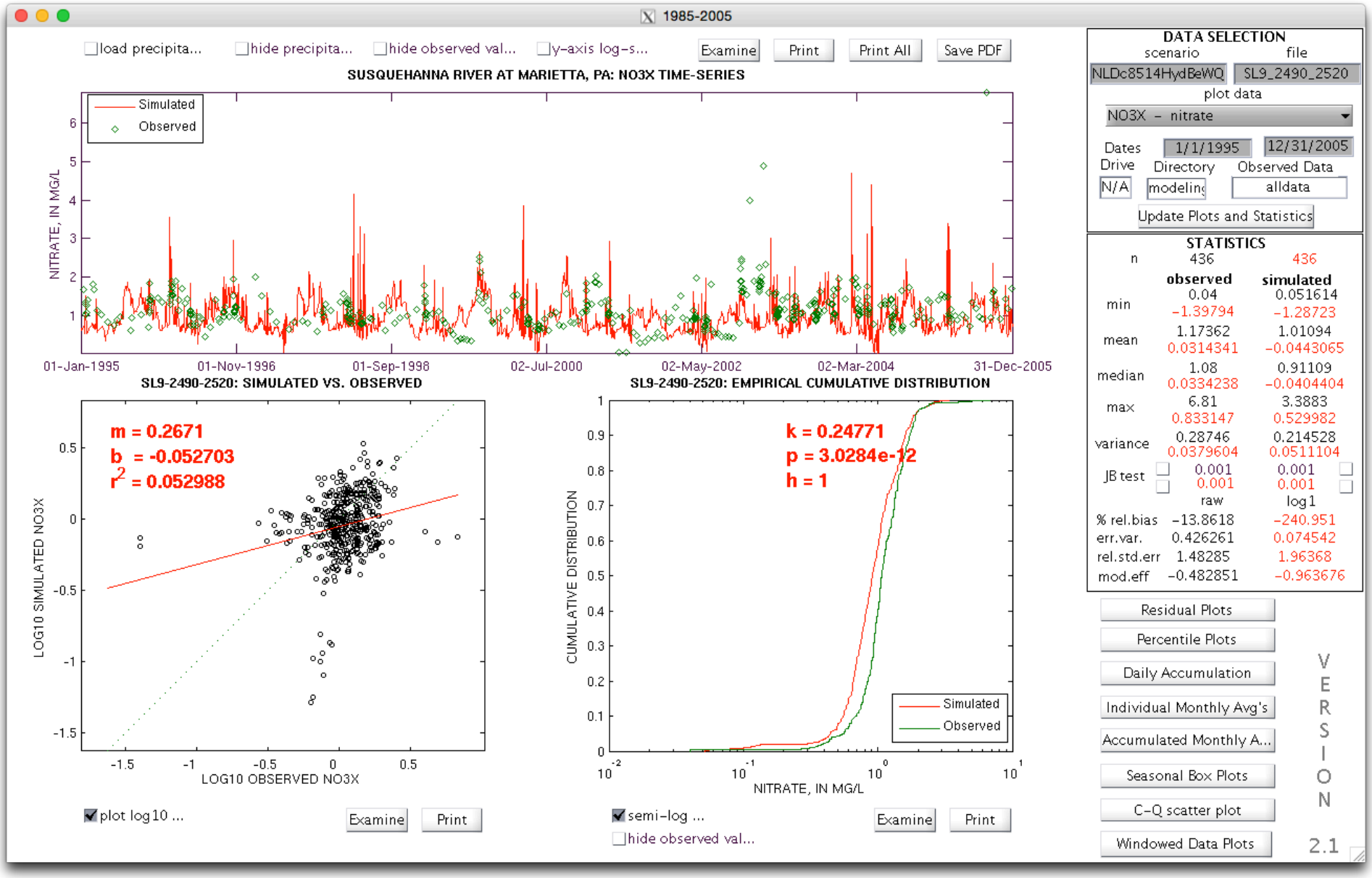
*Phase 5, **Nitrate**, Susquehanna at Marietta*



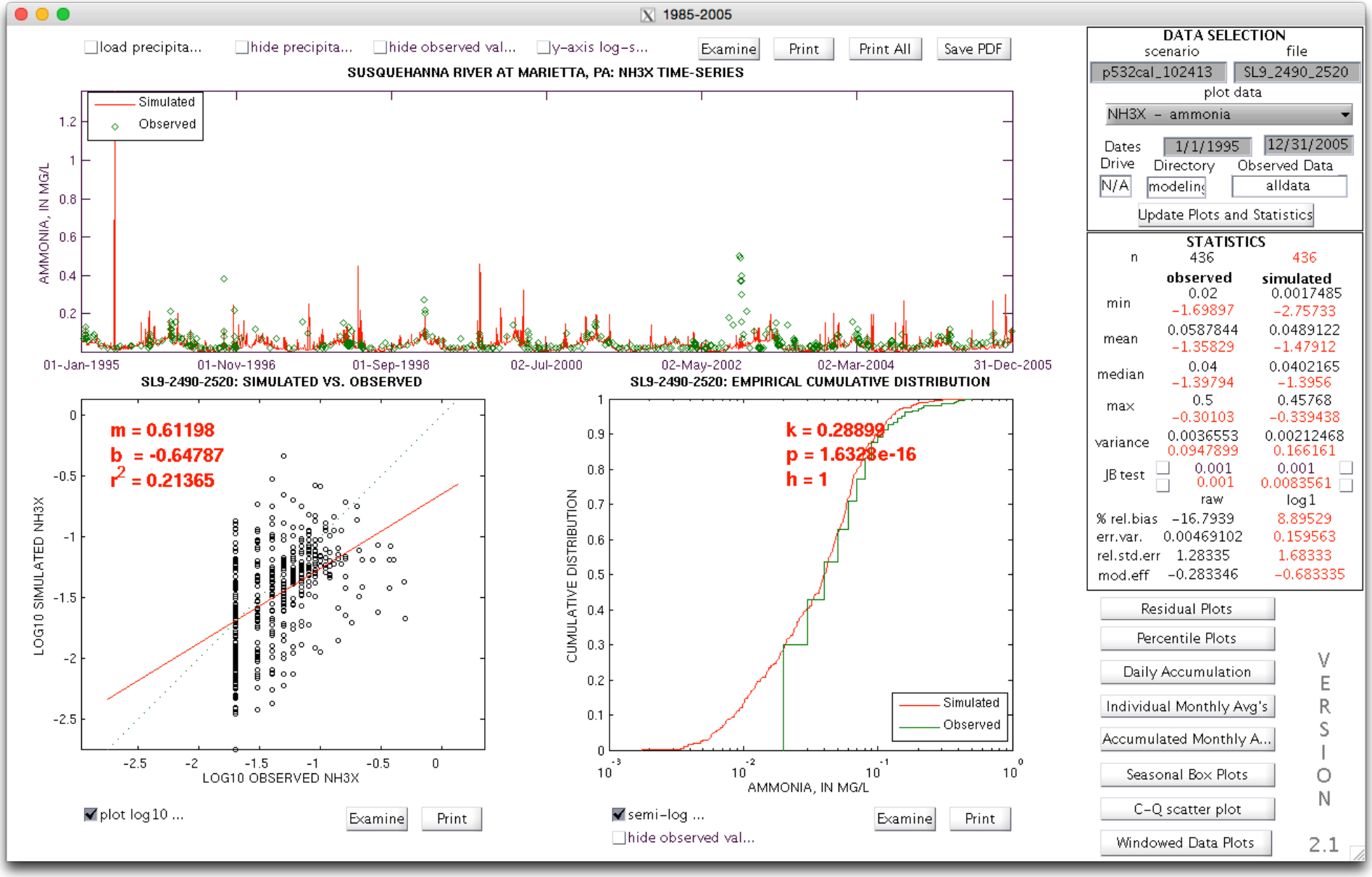
*Phase 6 Oct'14, **Nitrate**, Susquehanna at Marietta*



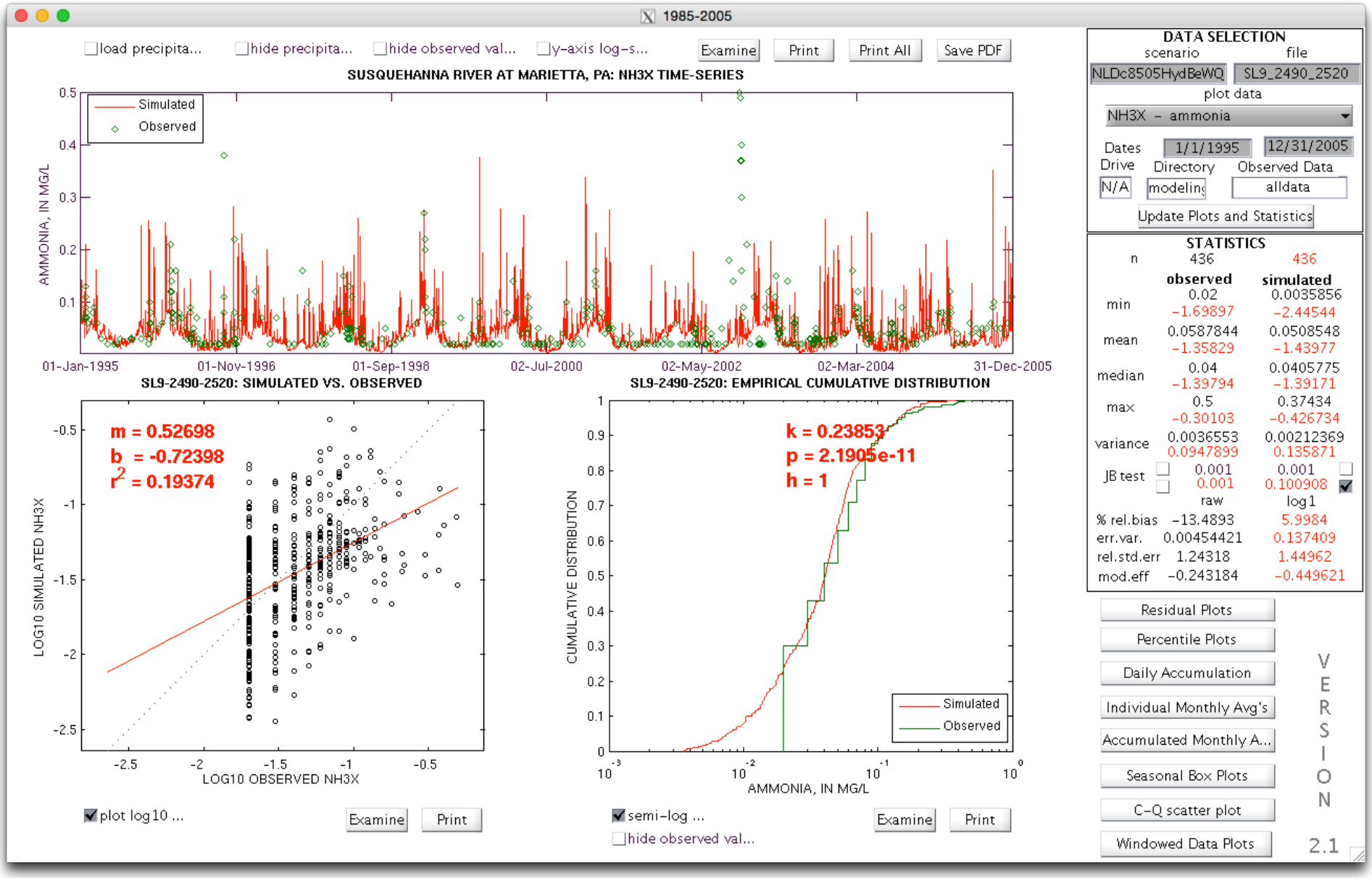
*Phase 6 Apr'15, **Nitrate**, Susquehanna at Marietta*



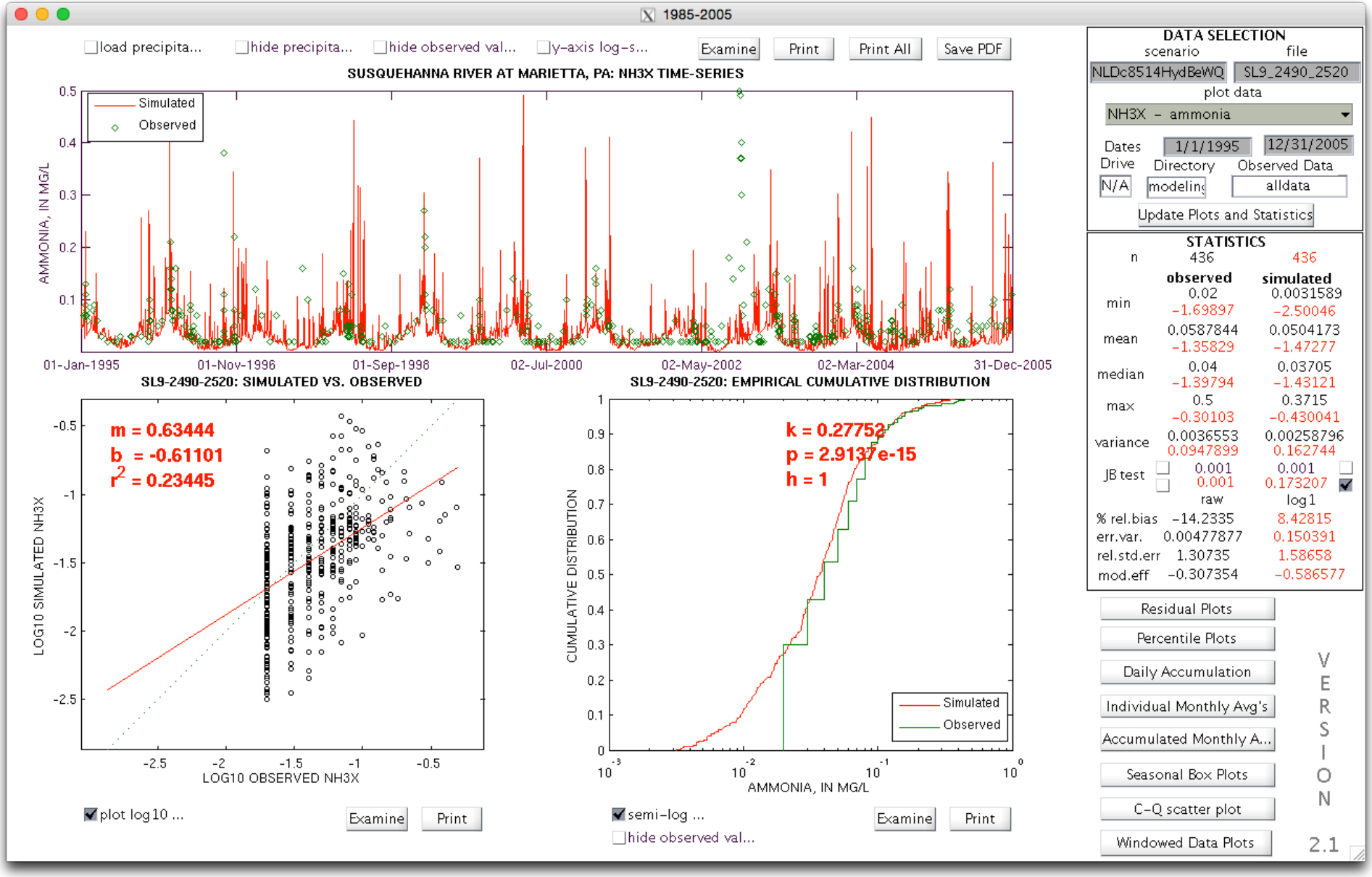
*Phase 5, **Ammonia**, Susquehanna at Marietta*



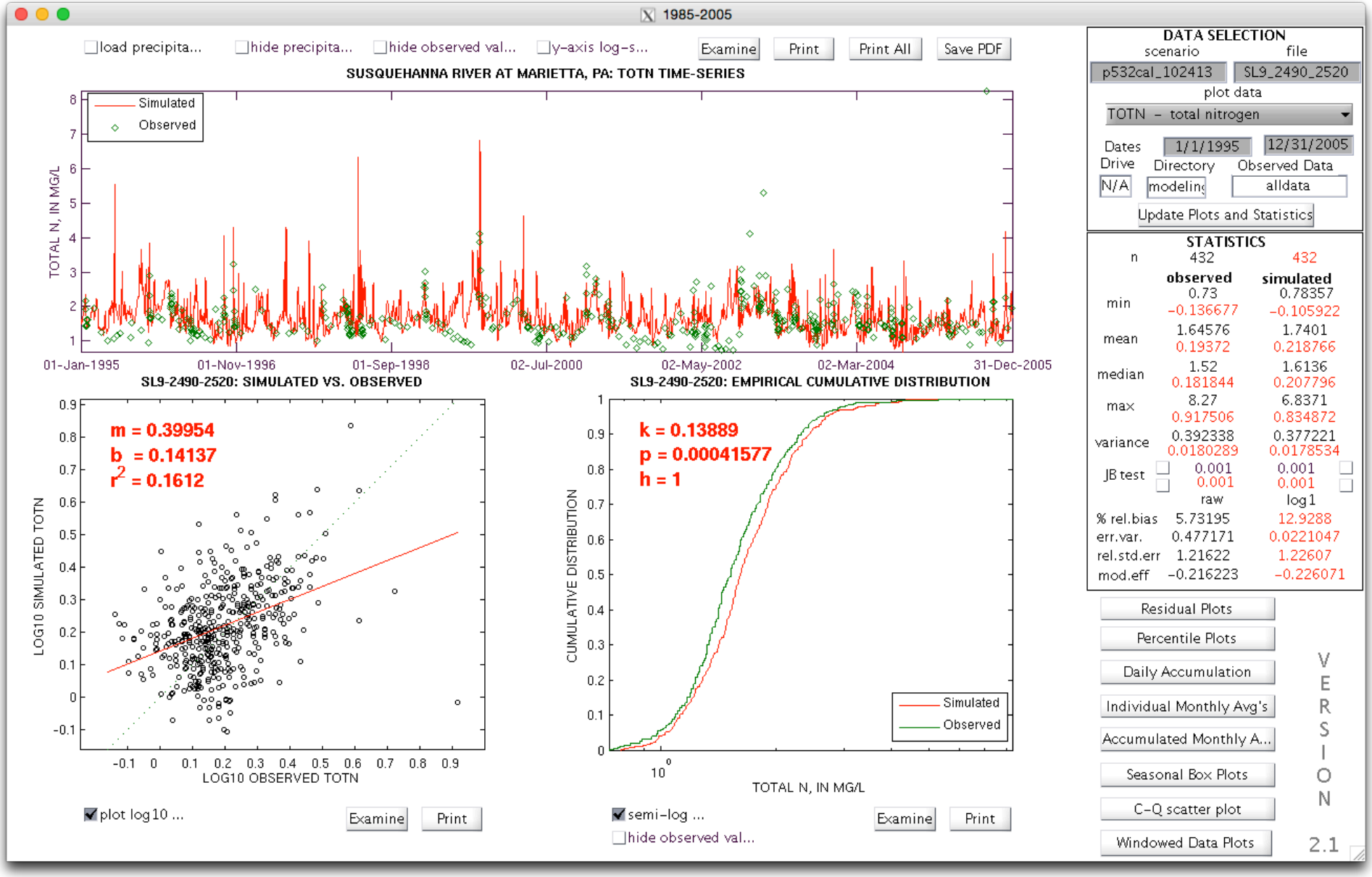
*Phase 6 Oct'14, **Ammonia**, Susquehanna at Marietta*



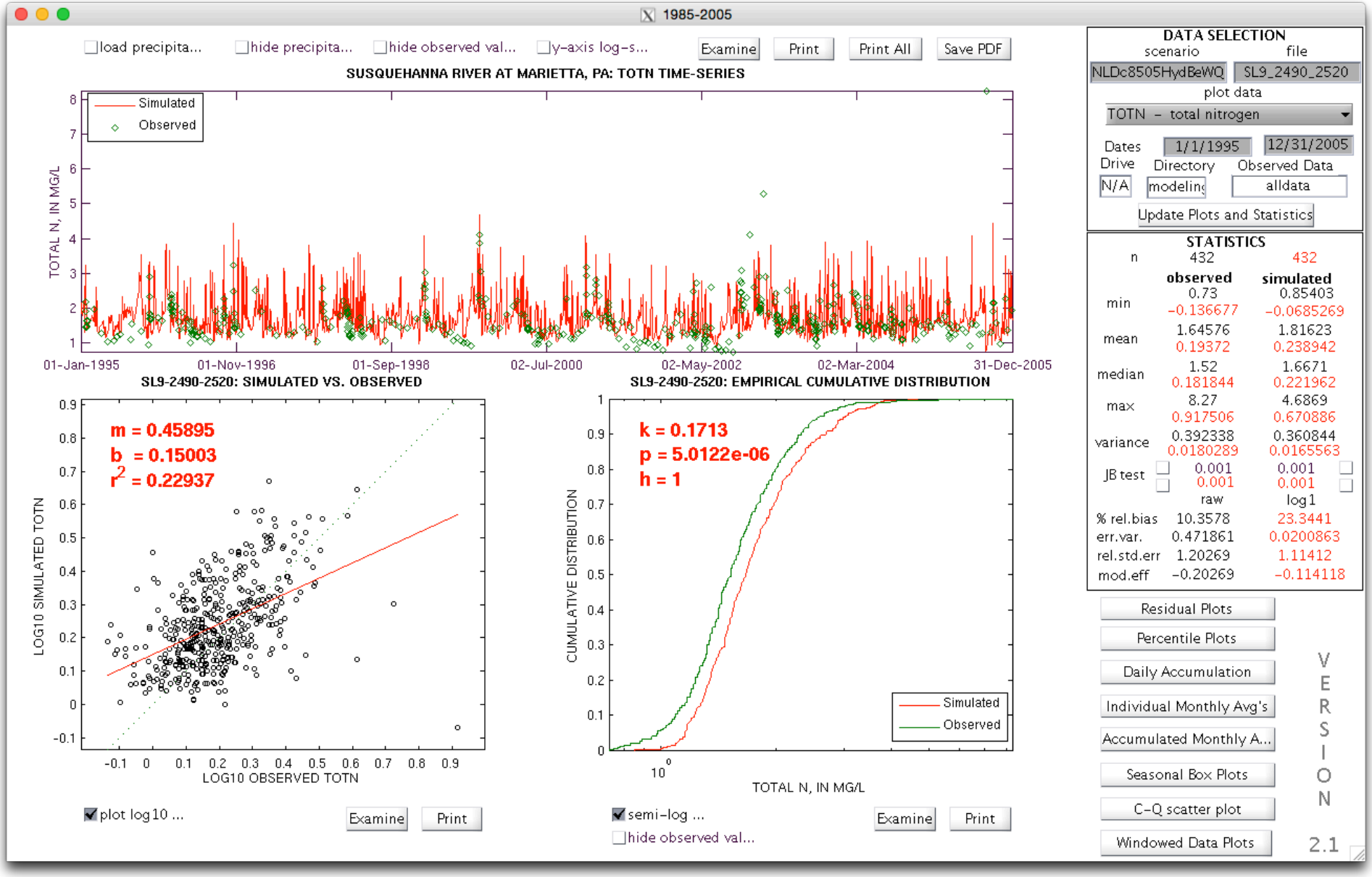
*Phase 6 Apr'15, **Ammonia**, Susquehanna at Marietta*



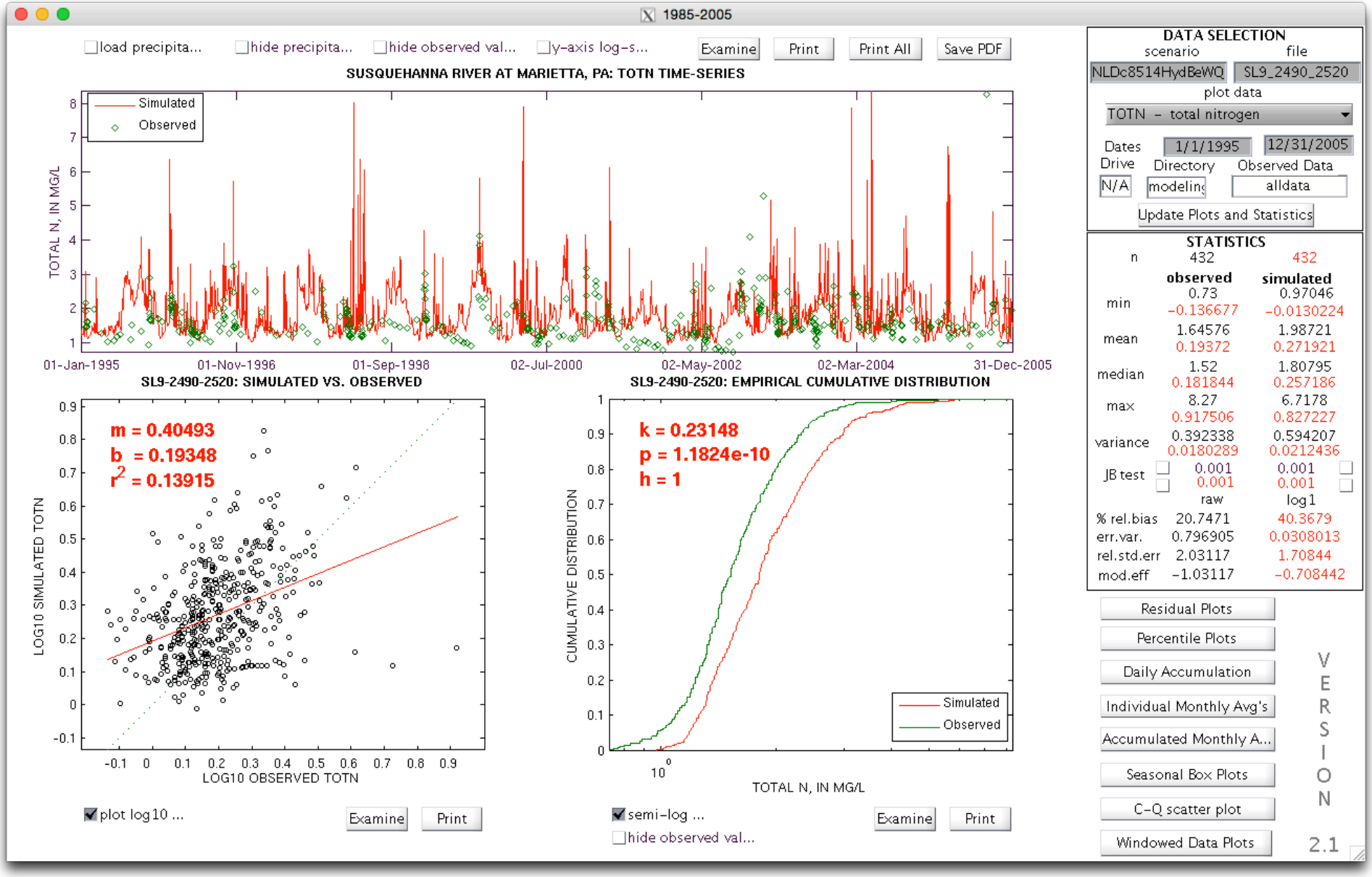
Phase 5, Nitrogen, Susquehanna at Marietta



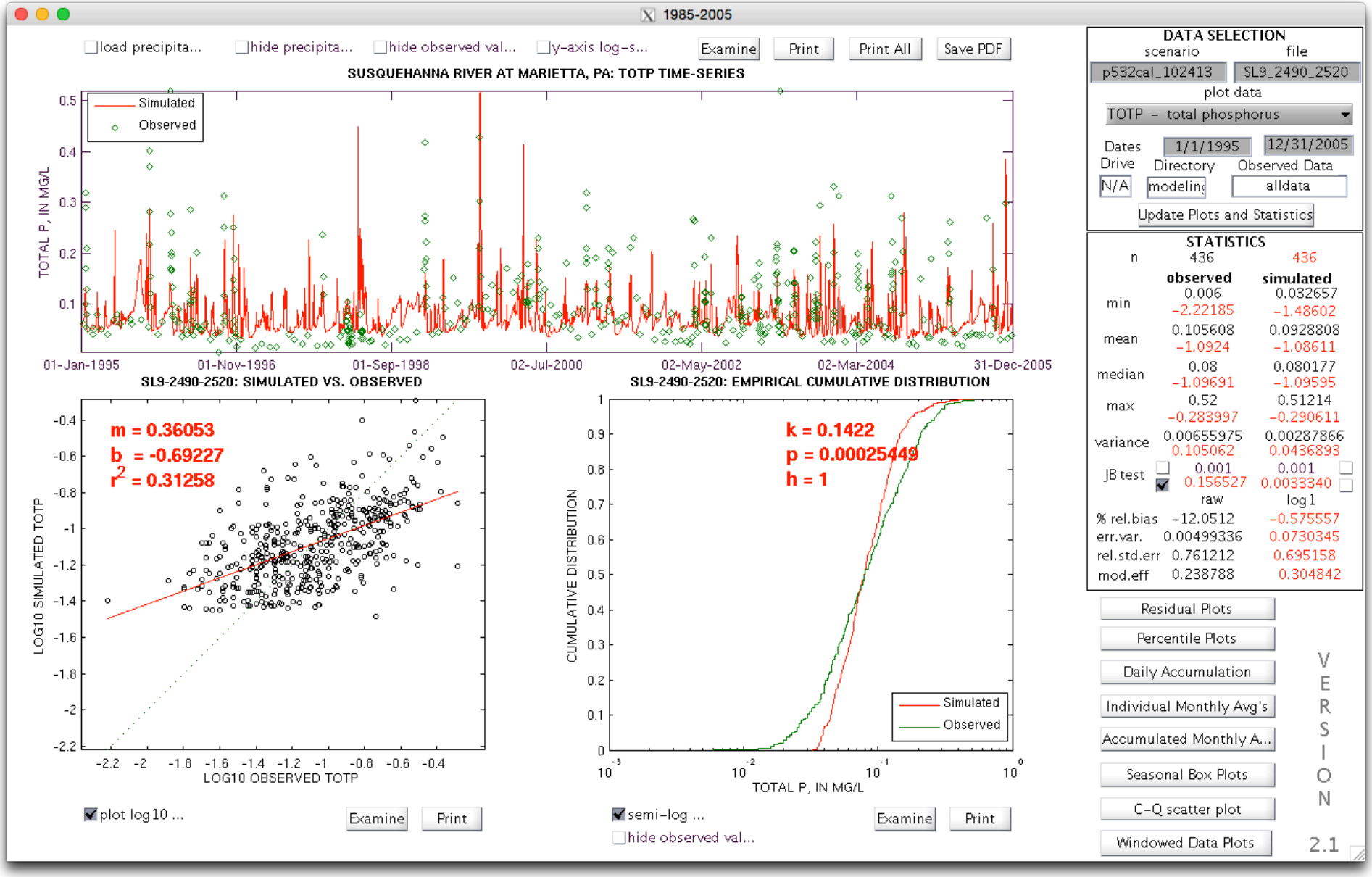
Phase 6 Oct'14, Nitrogen, Susquehanna at Marietta



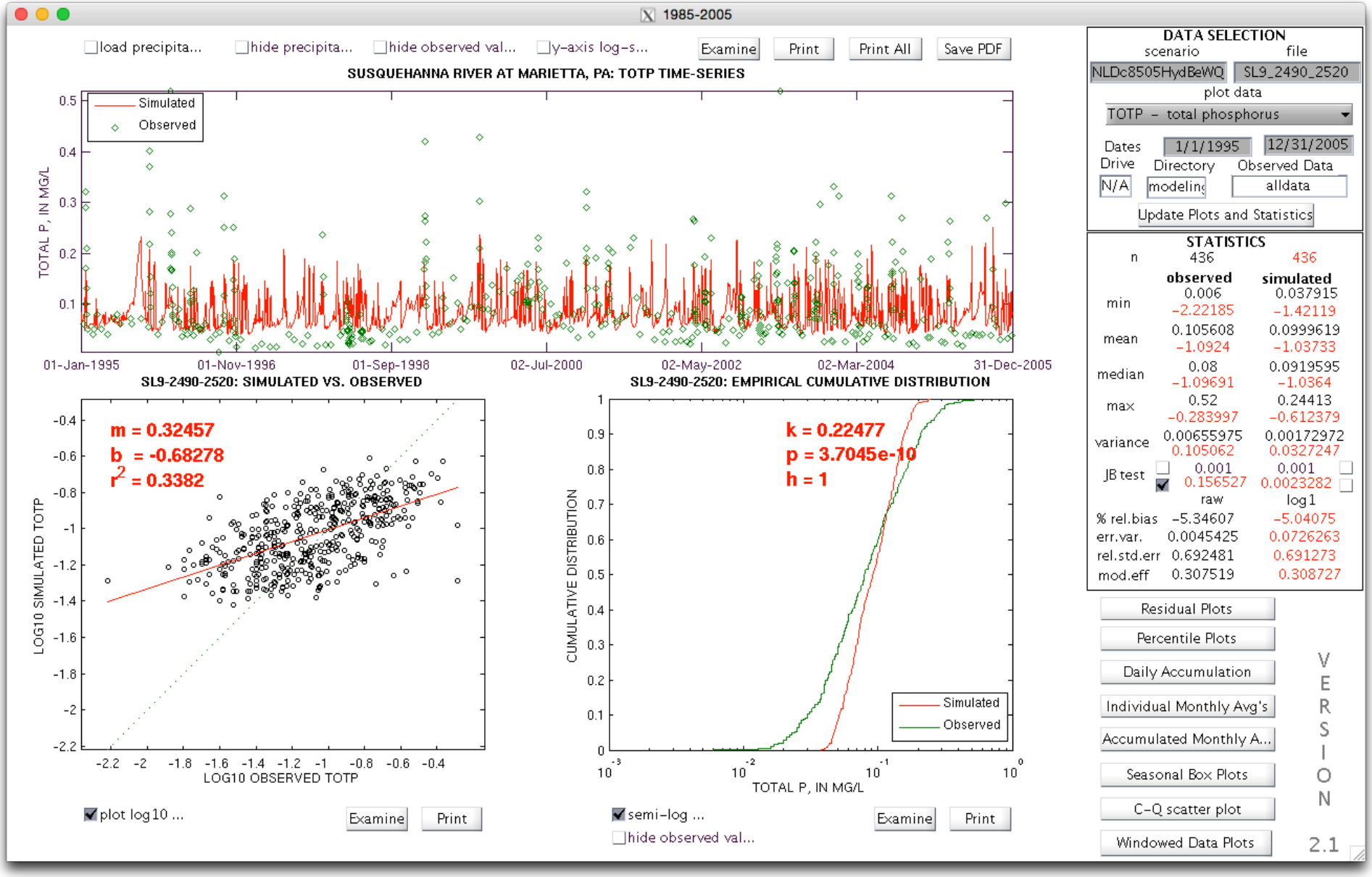
Phase 6 Apr'15, Nitrogen, Susquehanna at Marietta



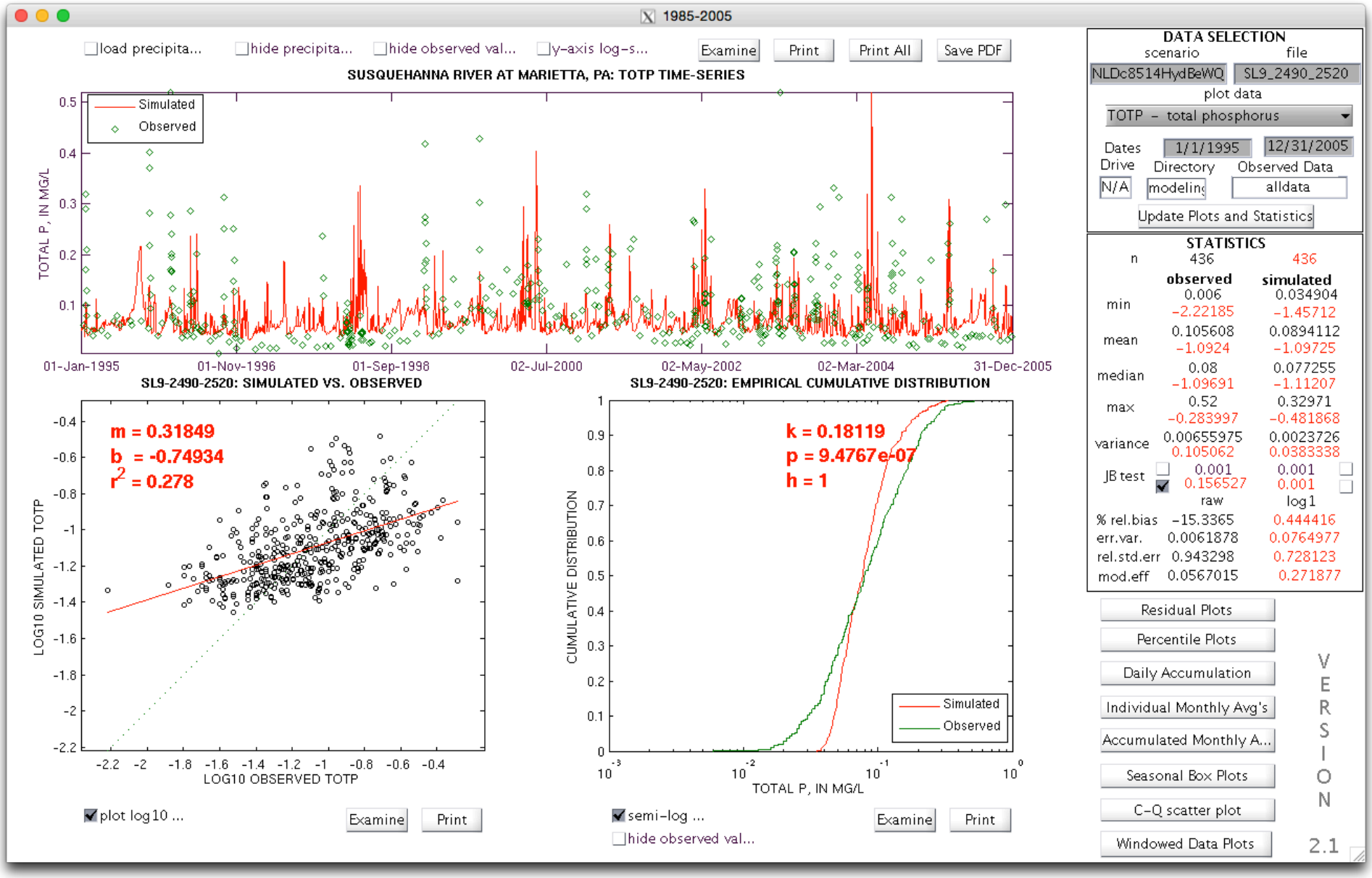
*Phase 5, **Phosphorous**, Susquehanna at Marietta*



*Phase 6 Oct'14, **Phosphorous**, Susquehanna at Marietta*

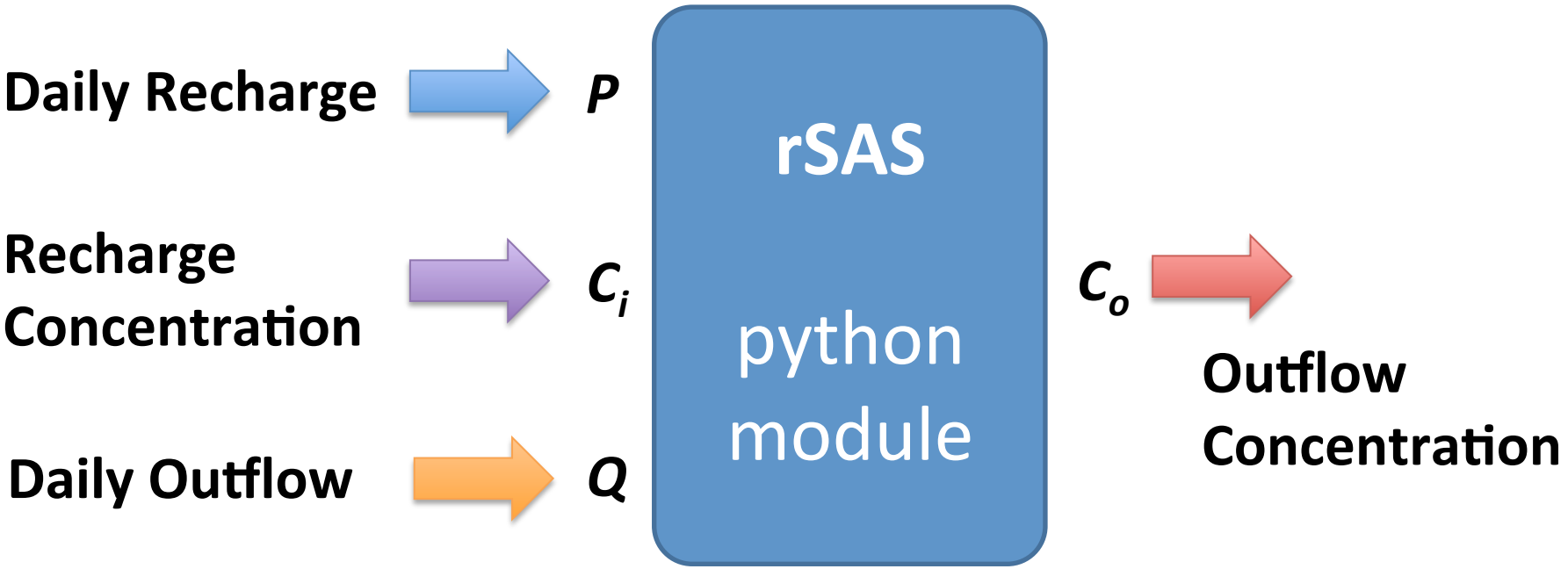


*Phase 6 Apr'15, **Phosphorous**, Susquehanna at Marietta*



2. *rSAS – **r**anked **S**tor**A**ge **S**election [steady-state TTD]*

rSAS for *groundwater nitrate* transport

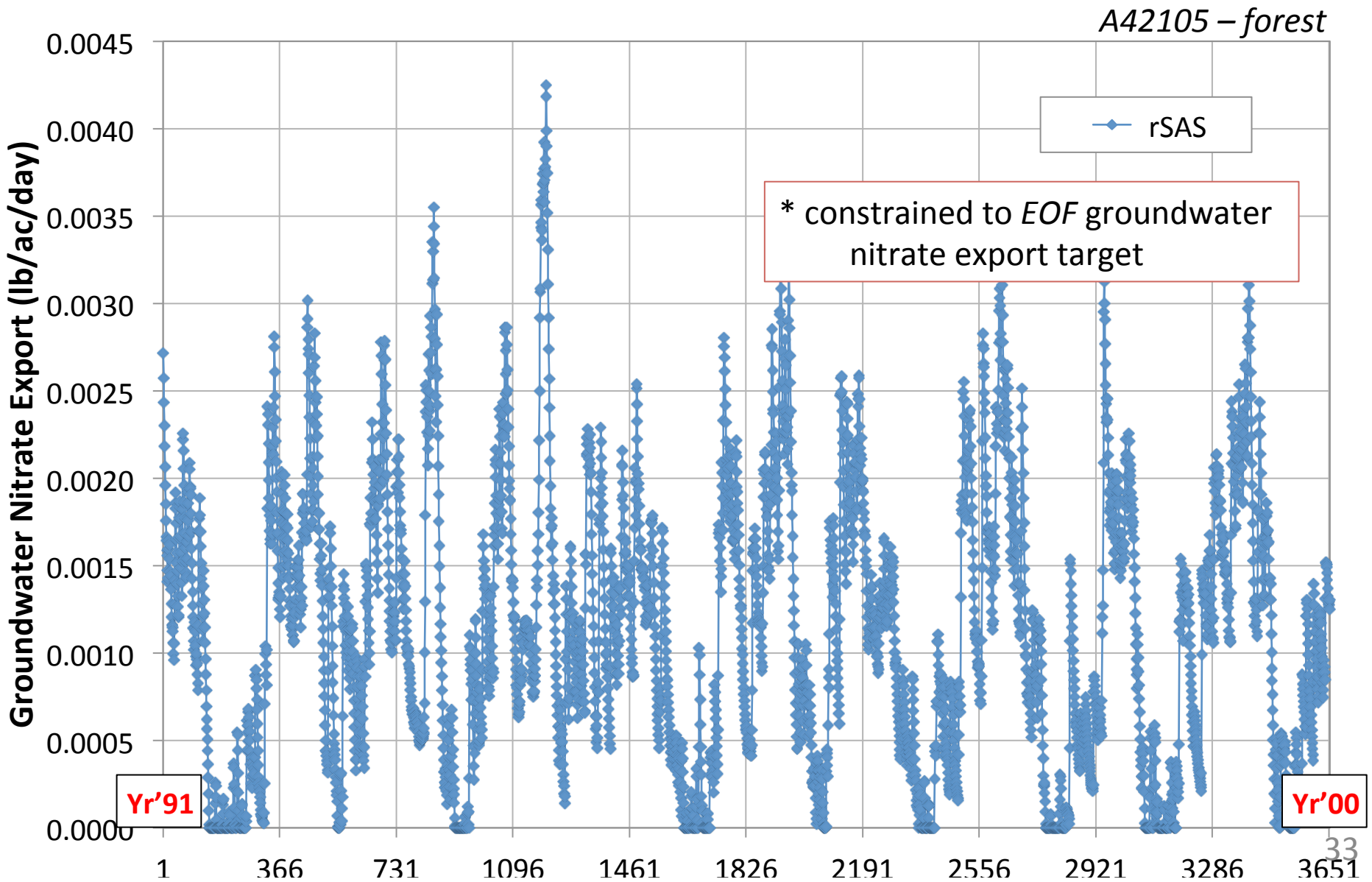


Addition Inputs

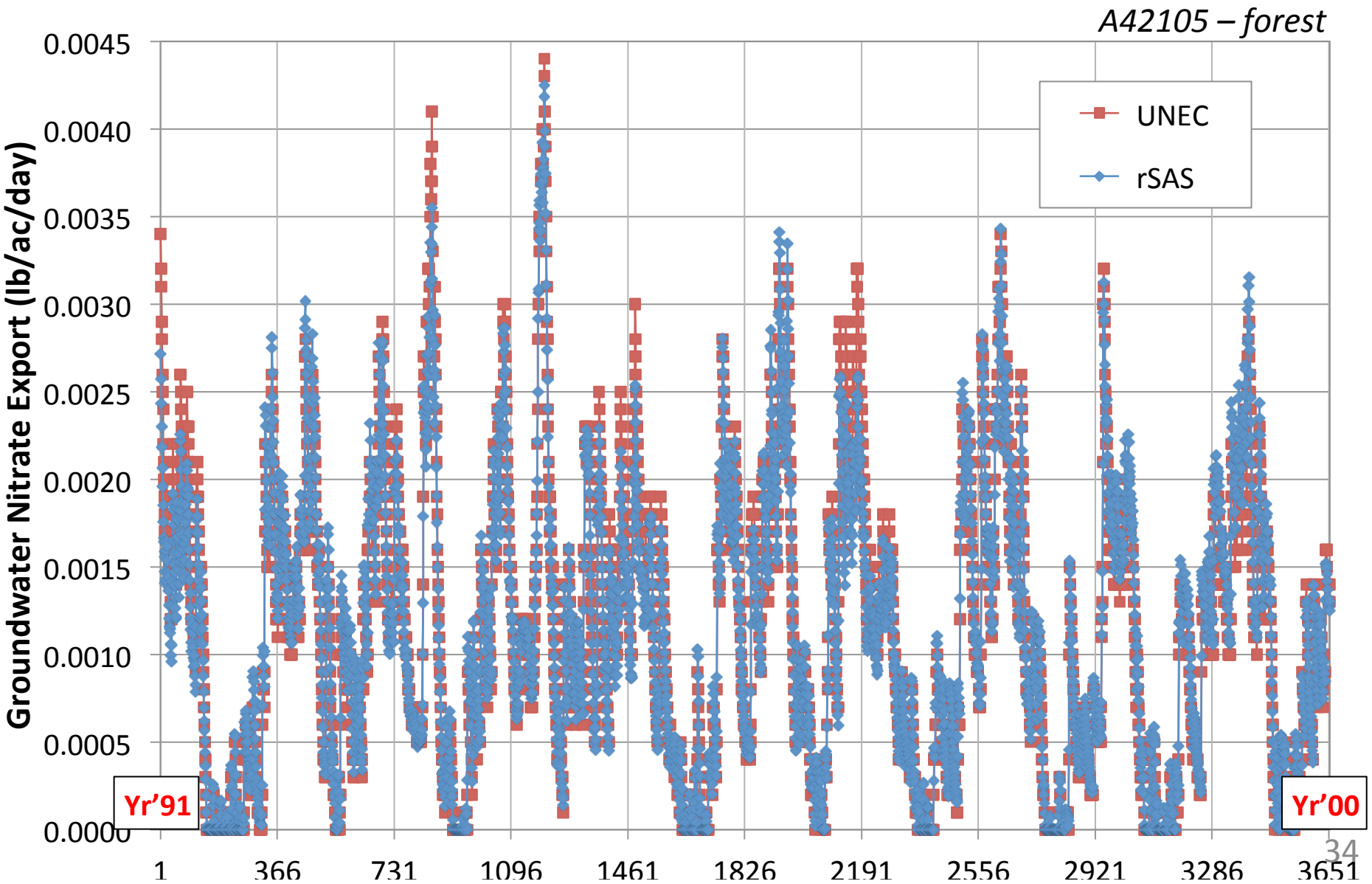
- **Steady State TTD**
- **rSAS Fn. Parameter**

- rSAS simulation from 1984 to 2005 was performed

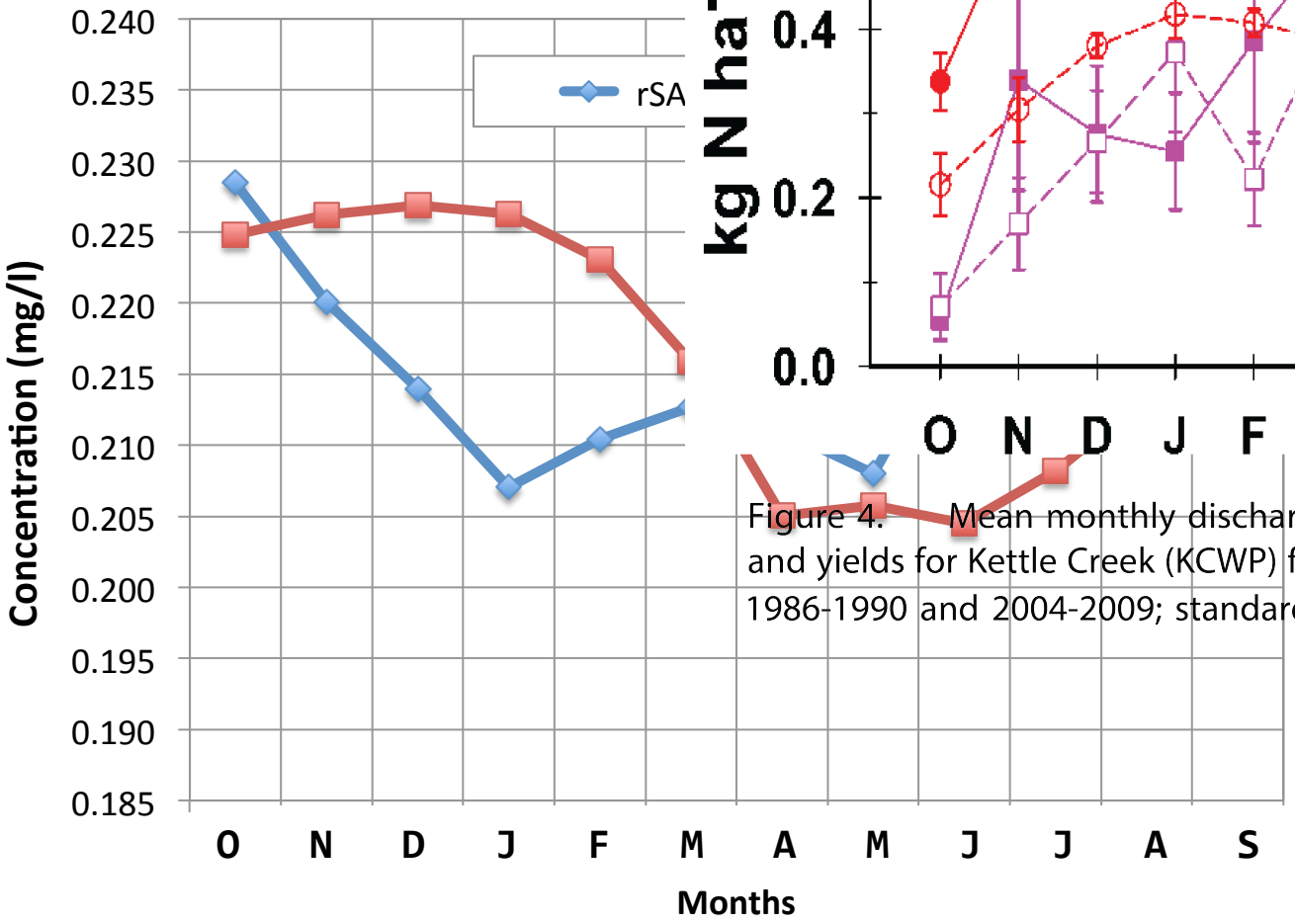
Simulated daily loads 1991-2000*



Simulated daily loads 1991-2000: rSAS vs. UNEC



Seasonality in Mean Groundwater Nitrate simulated using UNEC & rSAS (both uncalibrated)



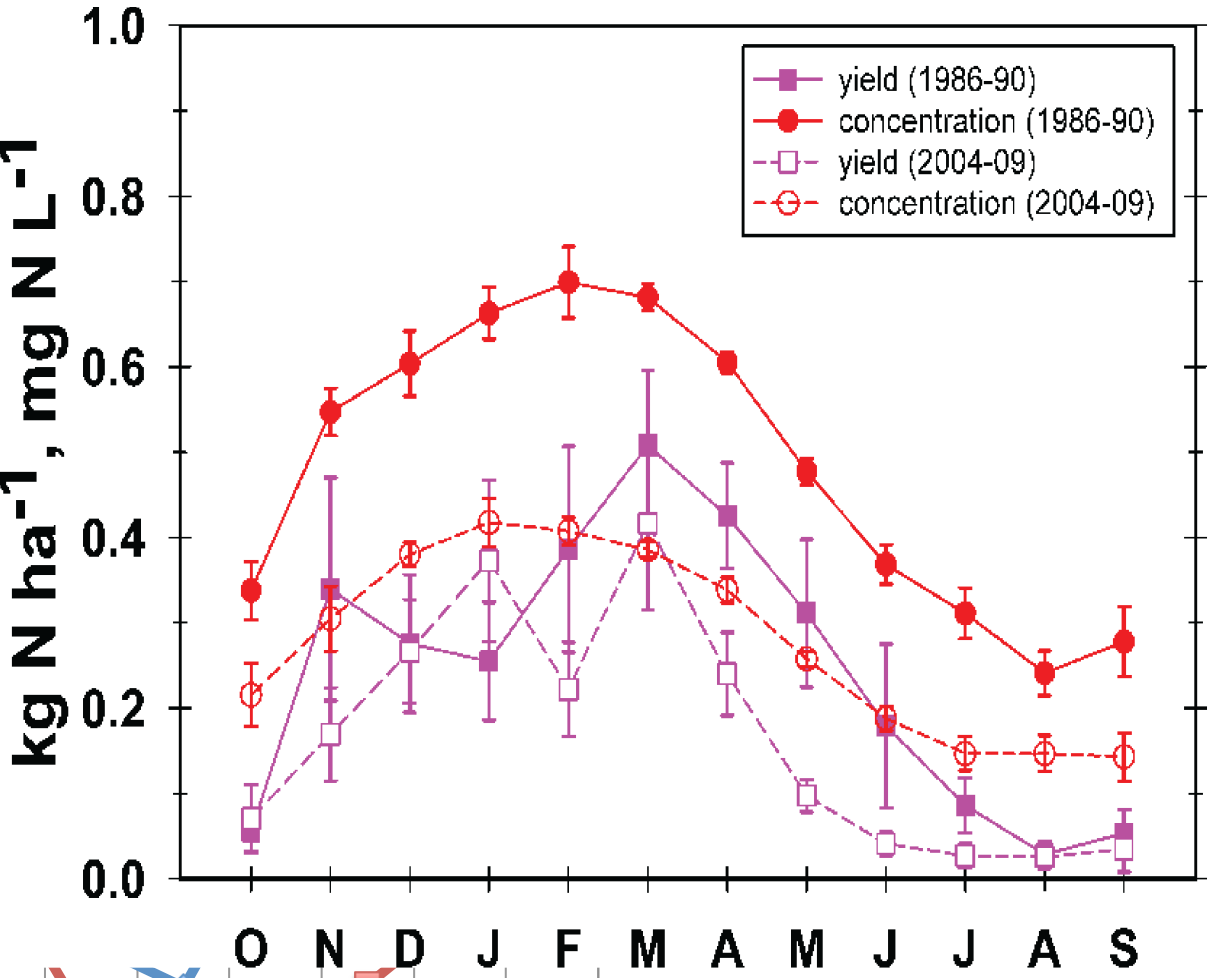
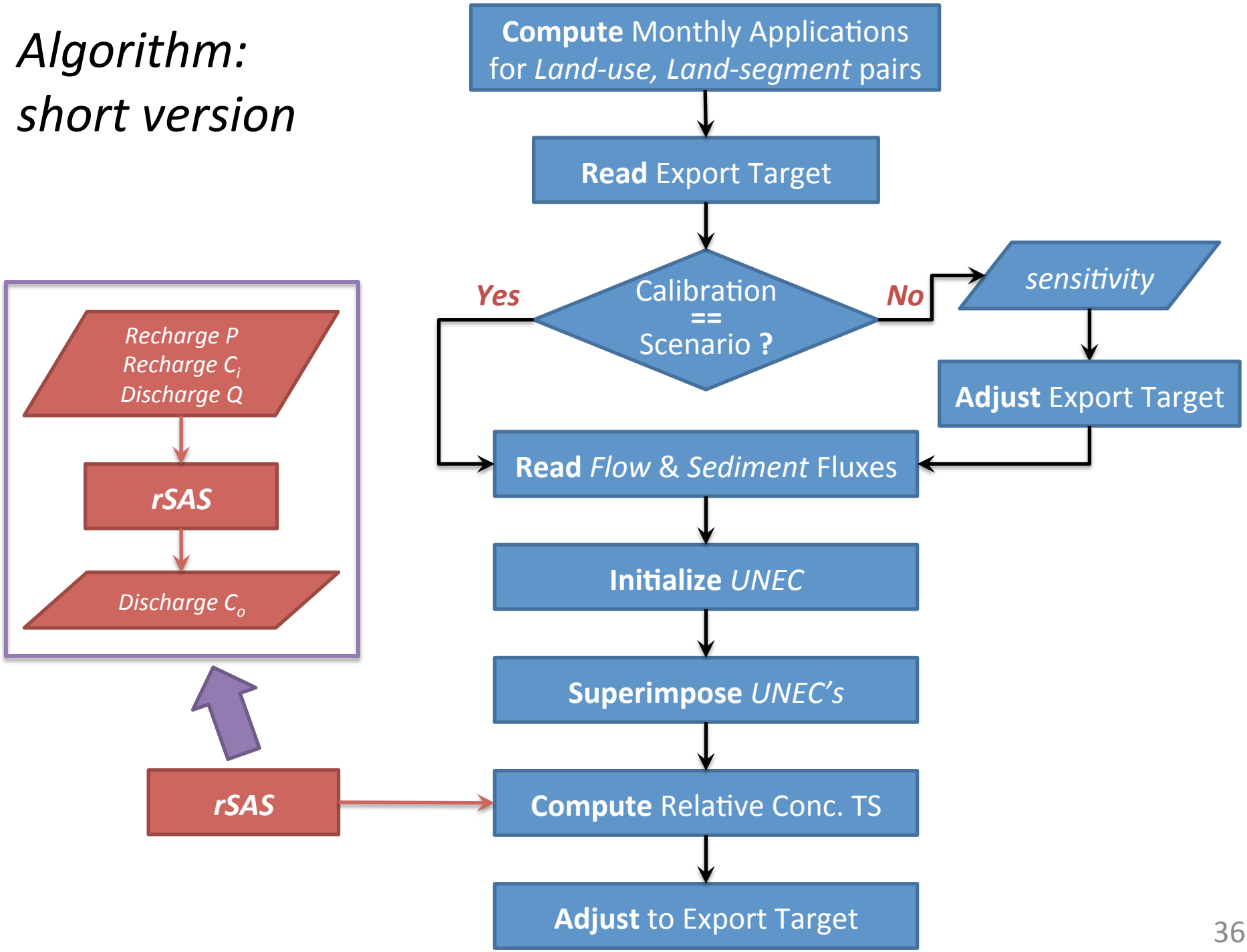


Figure 4. Mean monthly discharge-weighted nitrate-N concentrations and yields for Kettle Creek (KCWP) for two time periods: water years 1986-1990 and 2004-2009; standard errors also shown.

Algorithm: short version

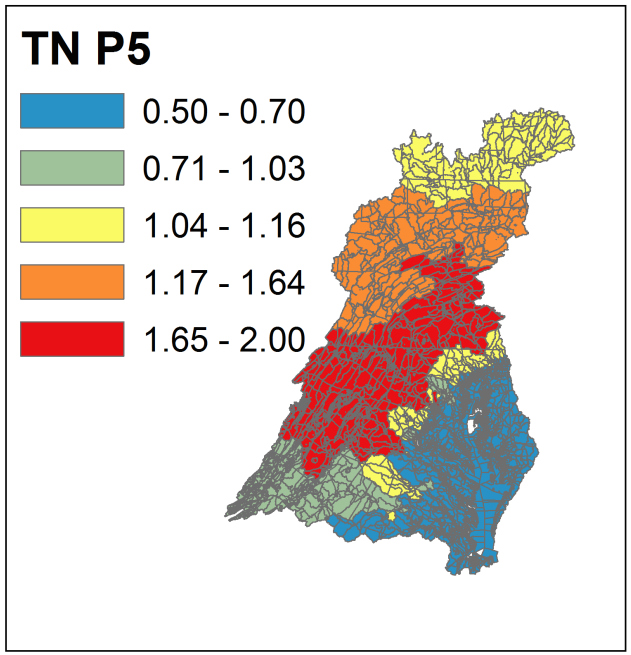


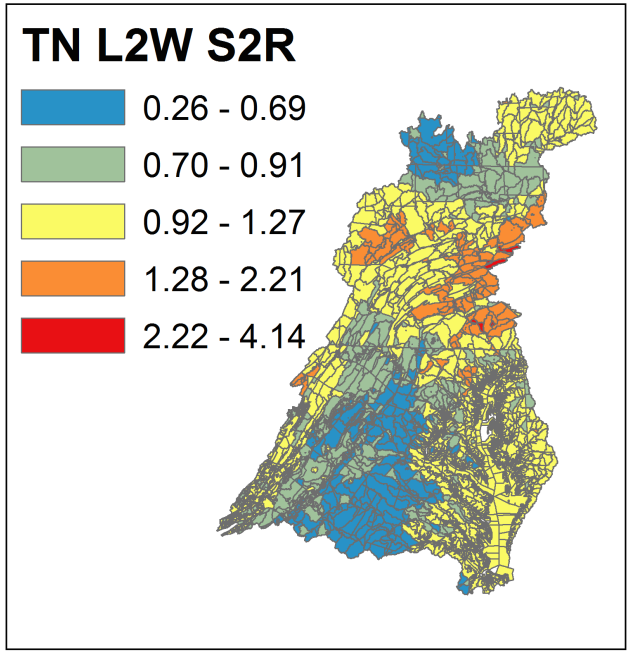
3. SPARROW based L2W, S2R variances

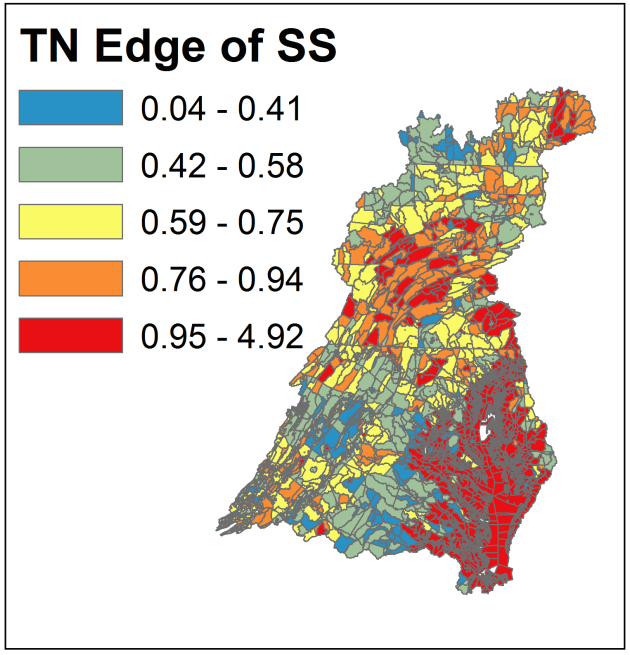
R. Mandel, G. Bhatt, G. Shenk, and others

Calibration	Description
Phase 5	Phase 5.3.2 (AGCHEM/PQUAL)
Phase 5 PQUAL	Phase 5, but PQUAL replaces AGCHEM
Phase 5 SPARROW	Phase 5 PQUAL with SPARROW transport factors in place of regional factors
Phase 5 Edge of SS	Phase 5 SPARROW with land simulation adjusted to SPARROW EOS loads

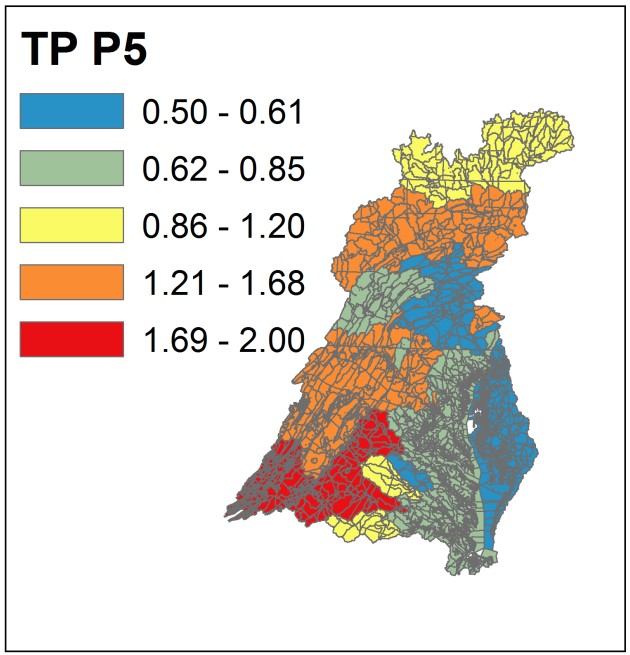
P5 transport factors vs. SPARROW derived variability

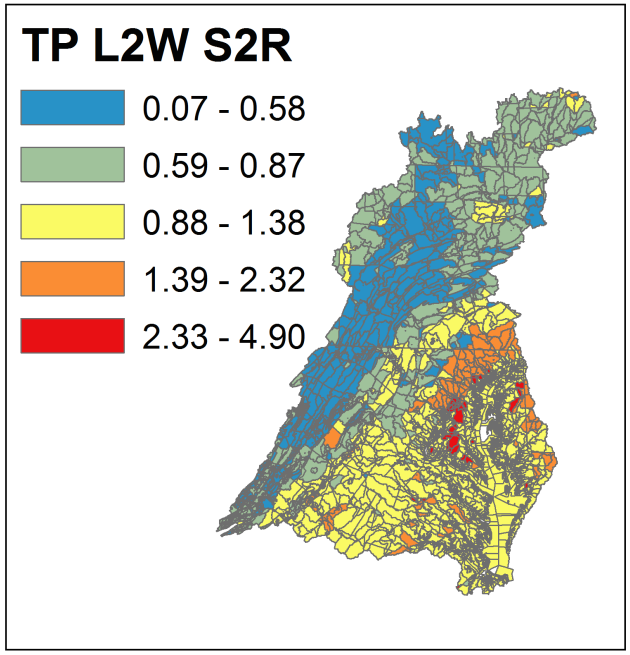


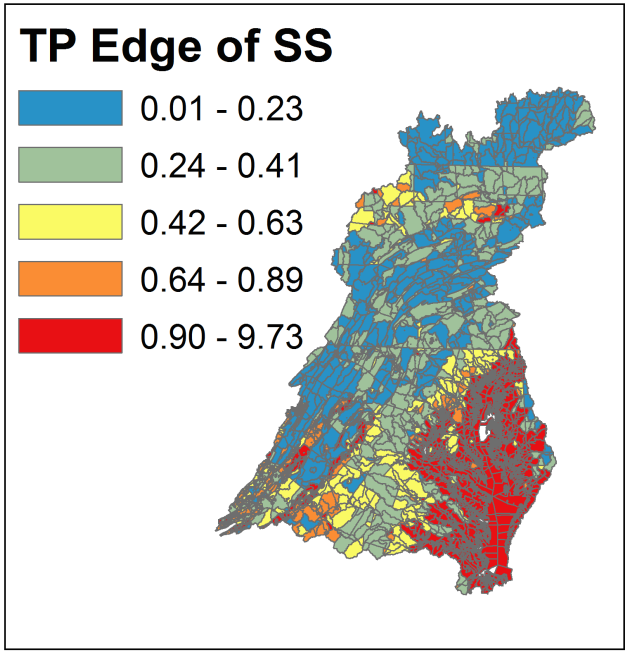




P5 transport factors vs. SPARROW derived variability







Conclusions

- Watershed model simulation was expanded to 2014.
- Watershed model performed as good as Phase 5, and in many cases better than the previous Phase 6 model prototype.
- Representation of lag-times were revised, which has resulted in some improvements in model performance and further performance improvements are expected.

Continued …

Conclusions

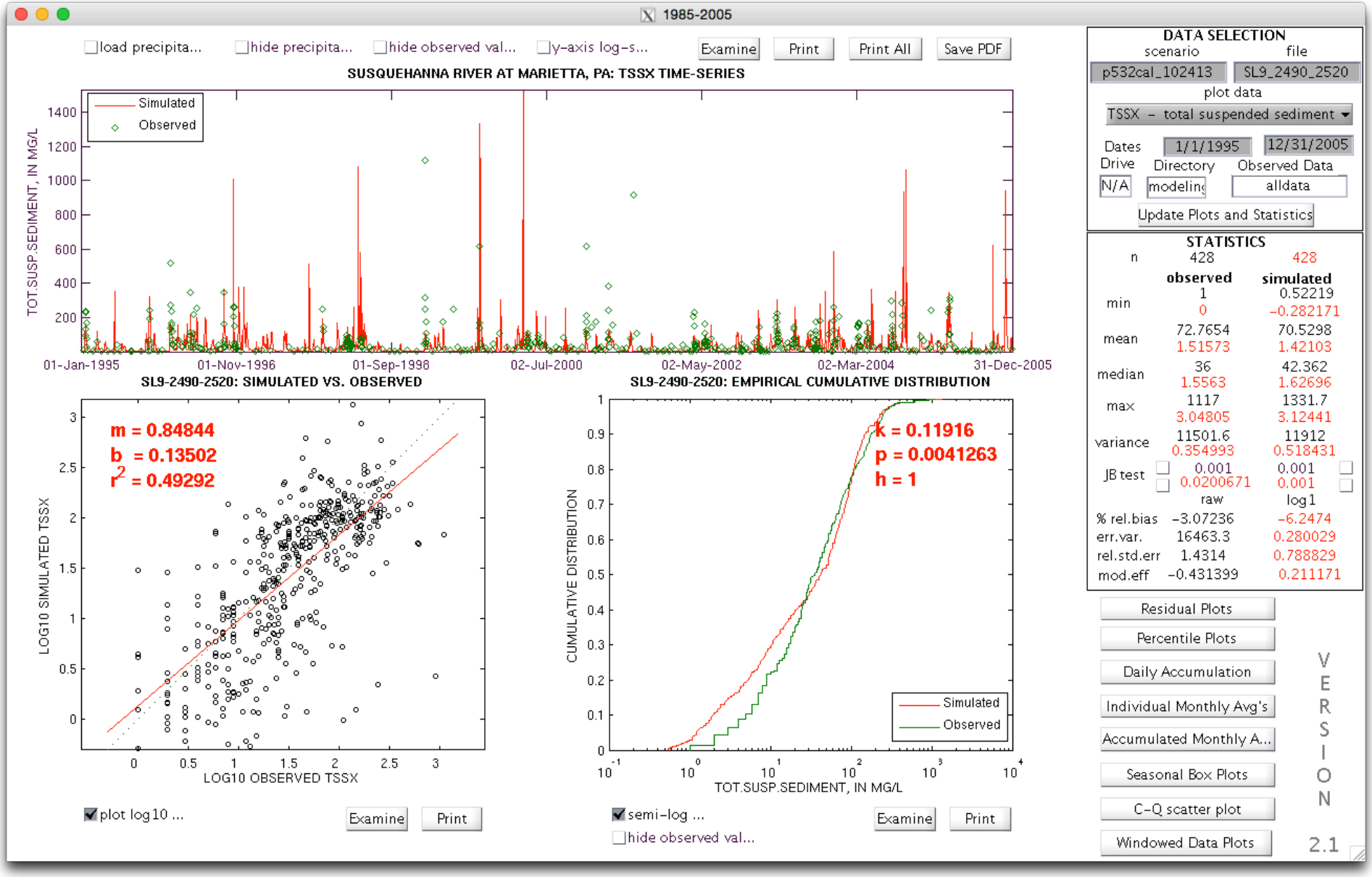
- A framework in Phase-6 model was developed to accept rSAS simulated outputs.
- Initial calibration runs were made based on SPARROW derived spatial variability.
- We have all the elements necessary, including the land-use, sensitivities, and targets, to produce the next refined prototype Phase 6 model for the July quarterly review.

Future work

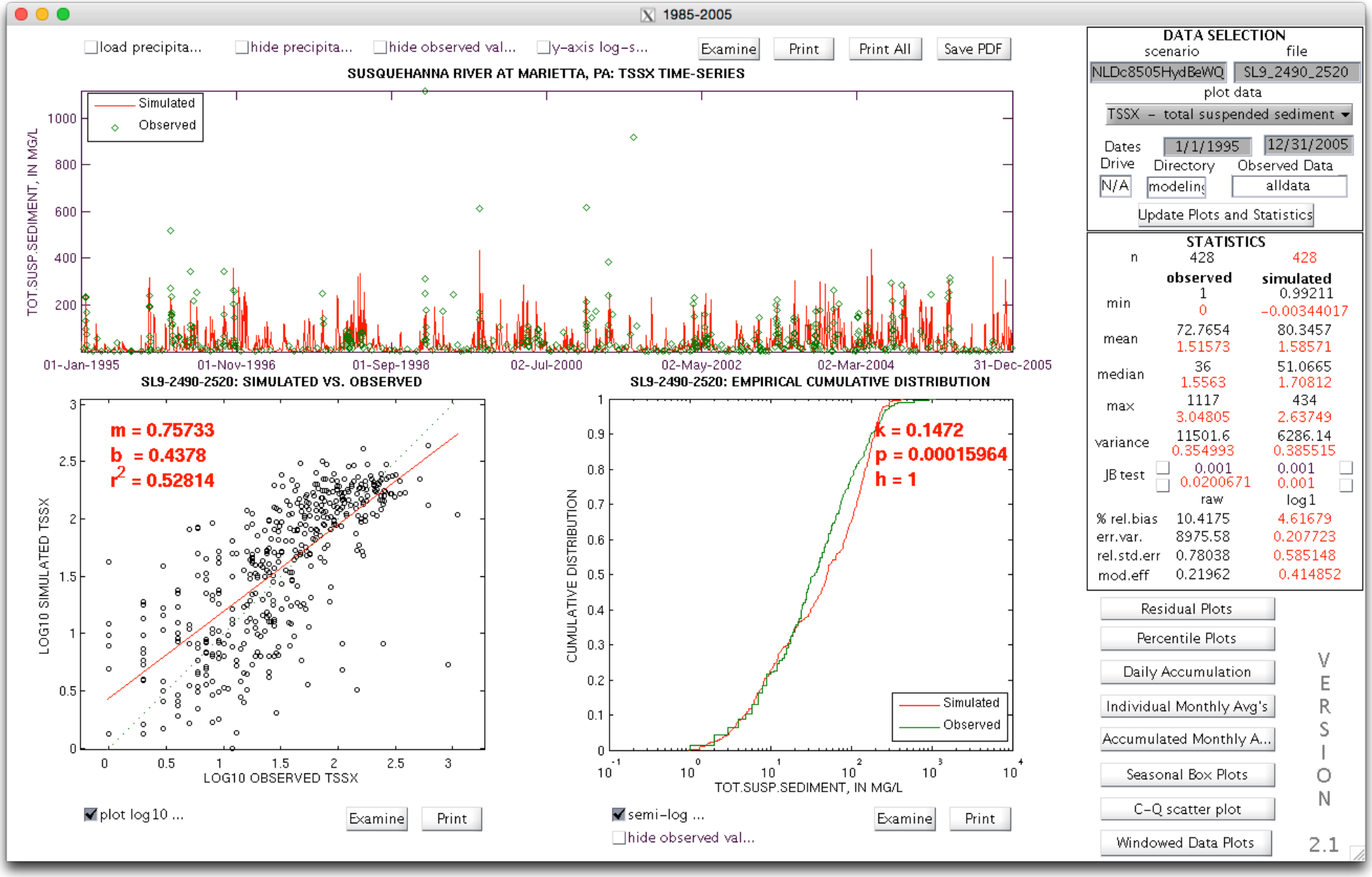
- Include recent *water quality* monitoring data in river calibration
- Integrate new streamflow, and water quality monitoring stations for calibration
- Calibrate watershed model where groundwater nitrate is simulated using rSAS *(would require information on TTD)*
- *Adjust lag-times specific to other nutrient species*
- *Investigate physiographic specific lag-times and special lag times such as in karst regions*
- Update model to accept Phase-6 land-uses, and export rates

Appendices

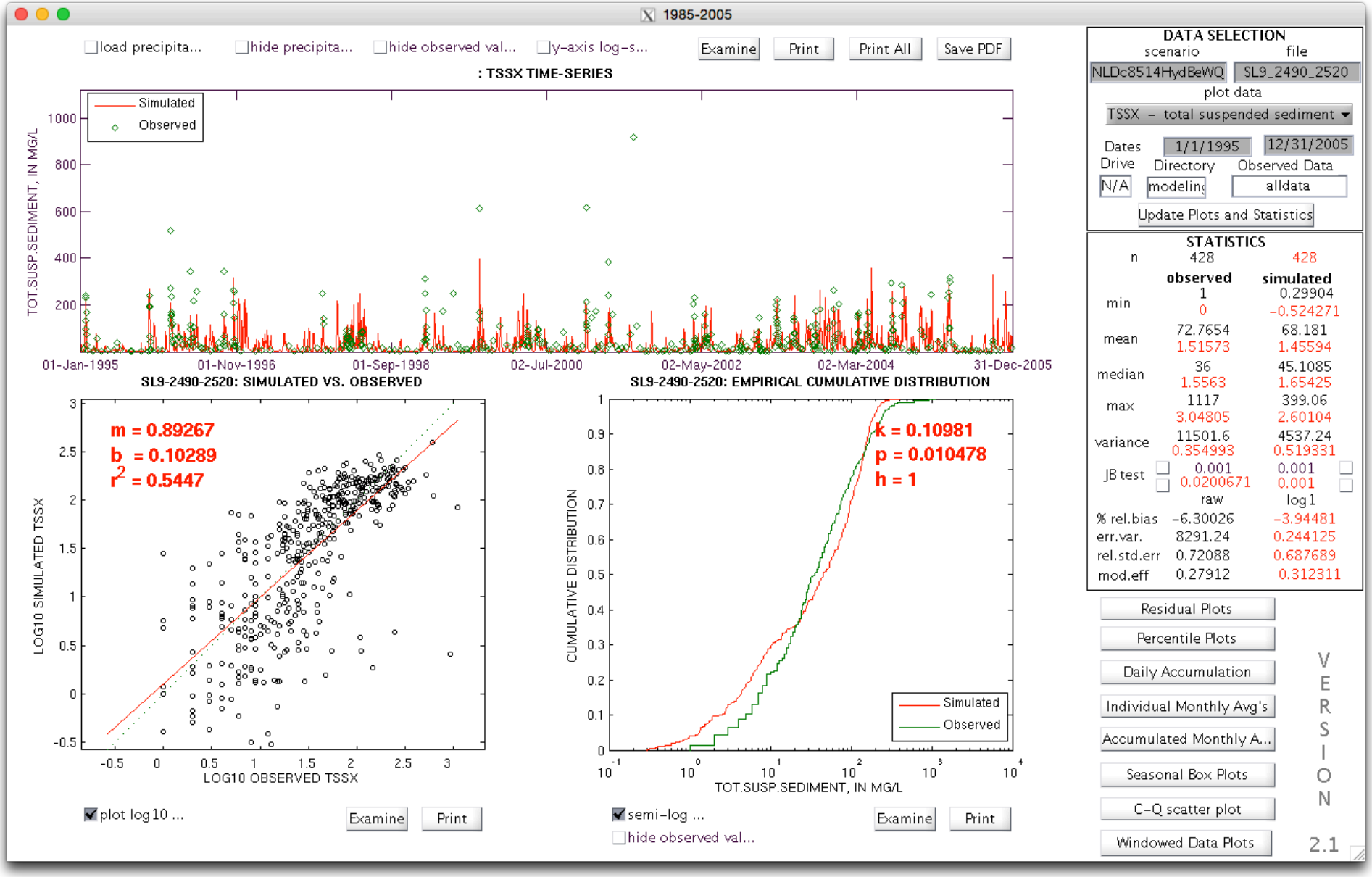
Phase 5, 1995-2005, TSS, Susquehanna at Marietta



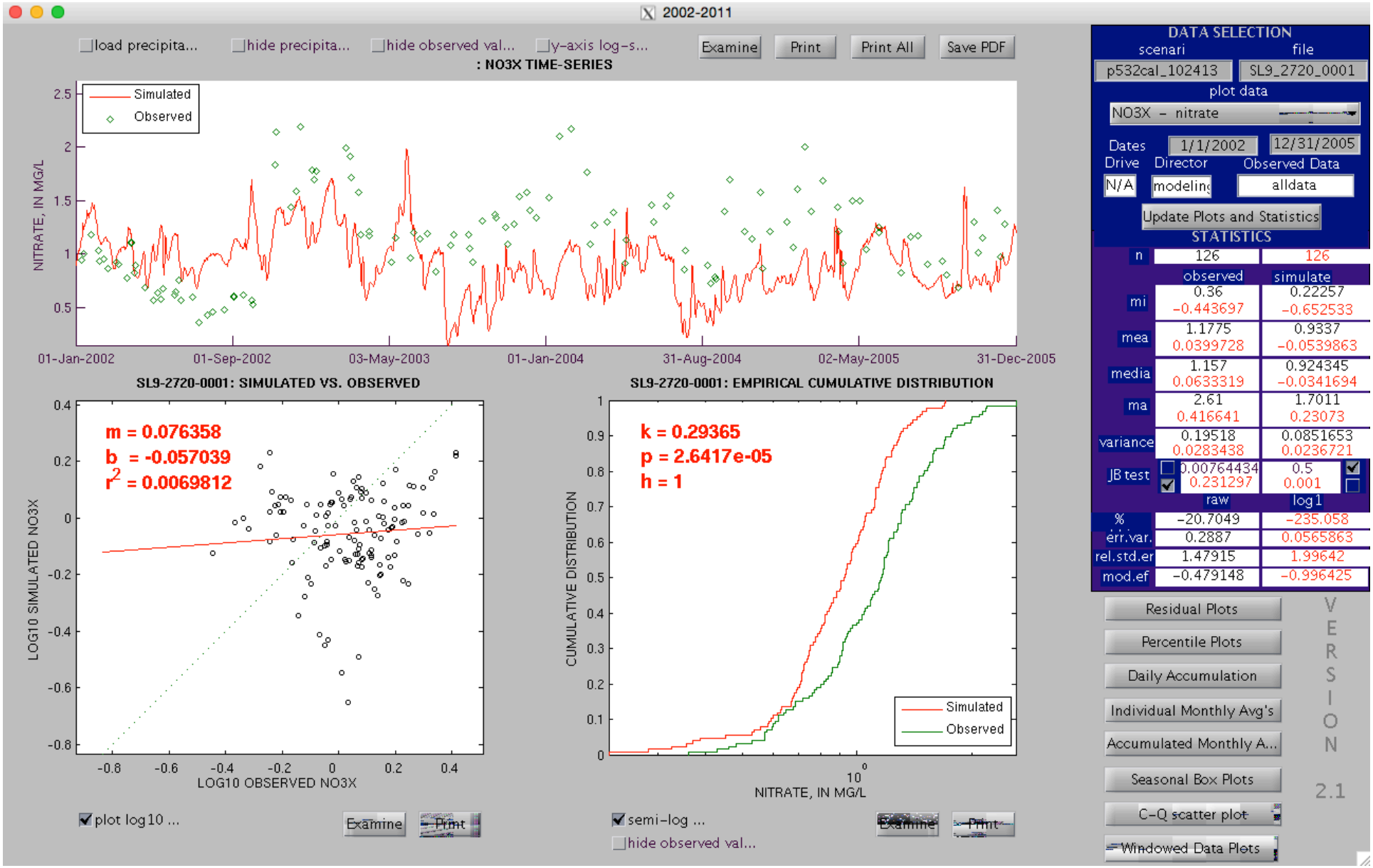
Phase 6 Oct'14, 1995-2005, TSS, Susquehanna at Marietta



Phase 6 Apr'15, 1995-2005, TSS, Susquehanna at Marietta

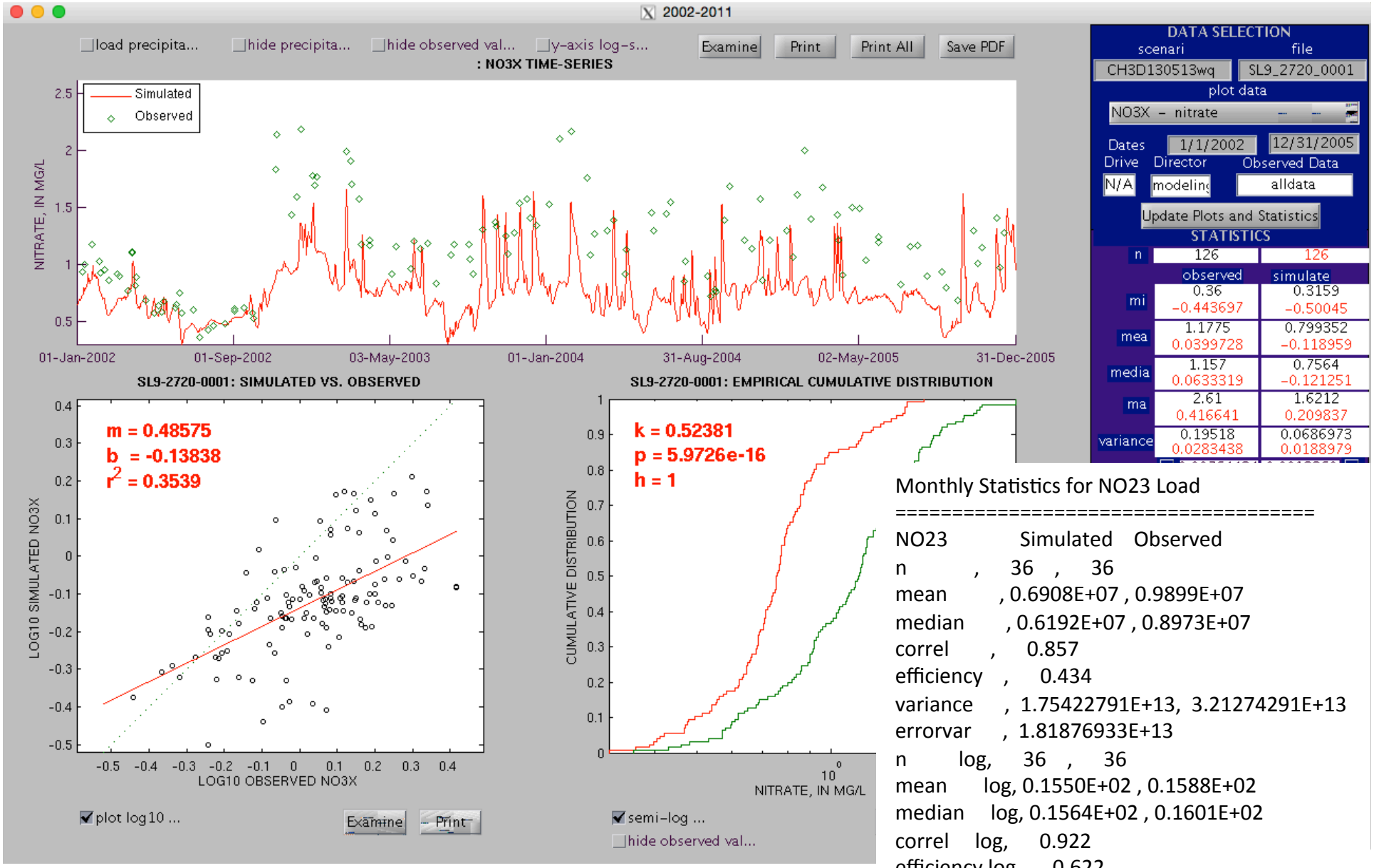


Phase 532 – NO3X – Susquehanna at Conowingo



nutrient simulation based on AGCHEM/PQUAL

Yrs02-11 (v1) – NO3X – Susquehanna at Conowingo



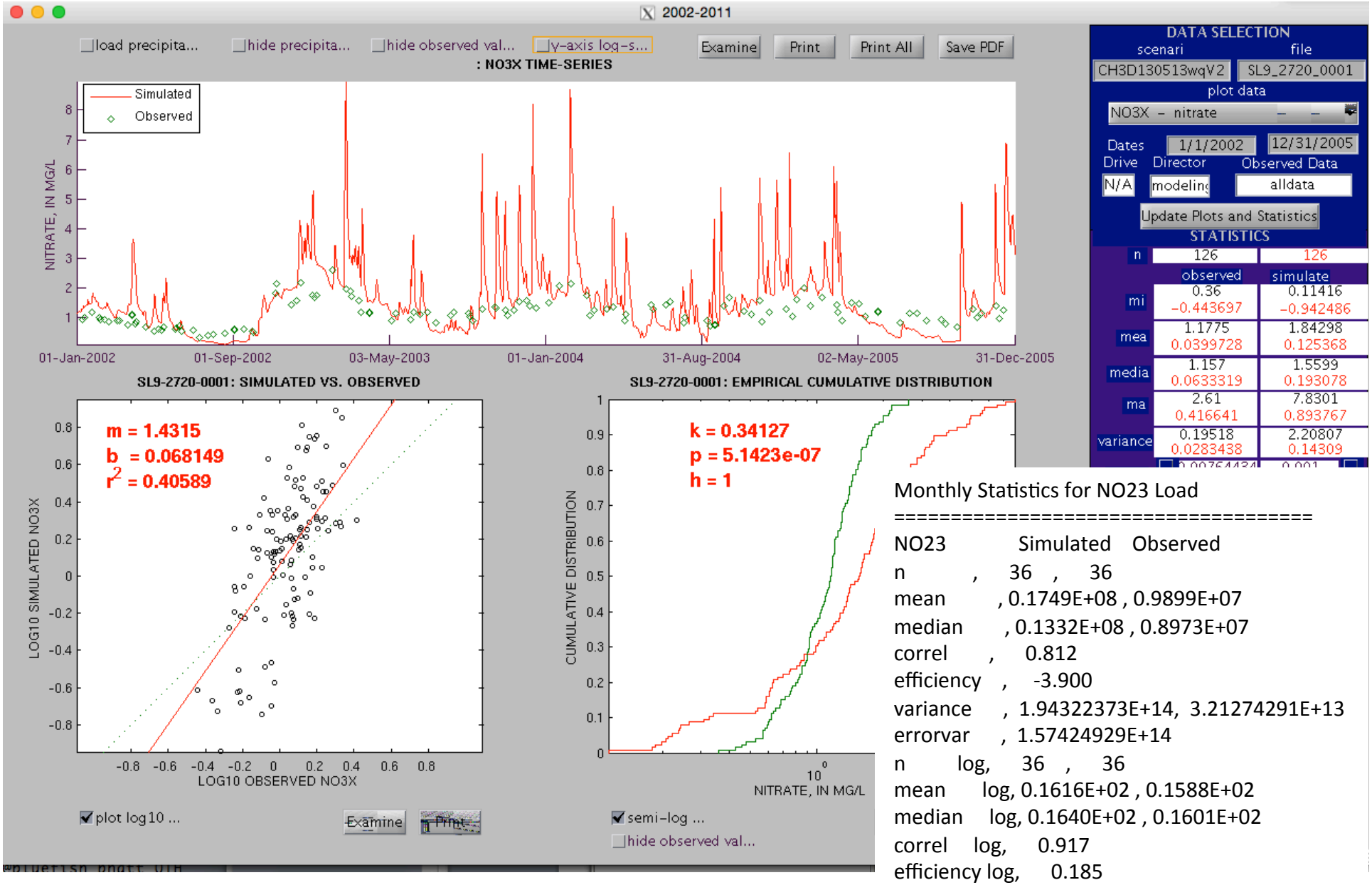
Monthly Statistics for NO23 Load

==========

NO23	Simulated	Observed
n	36	36
mean	0.6908E+07	0.9899E+07
median	0.6192E+07	0.8973E+07
correl	0.857	
efficiency	0.434	
variance	1.75422791E+13	3.21274291E+13
errorvar	1.81876933E+13	
n log,	36	36
mean log,	0.1550E+02	0.1588E+02
median log,	0.1564E+02	0.1601E+02
correl log,	0.922	
efficiency log,	0.622	
variance log,	0.7210E+00	0.6827E+00
errorvar log,	0.258	

nutrient simulation based on PQUAL

Yrs02-11 (v2) – NO3X – Susquehanna at Conowingo



Monthly Statistics for NO23 Load

==========

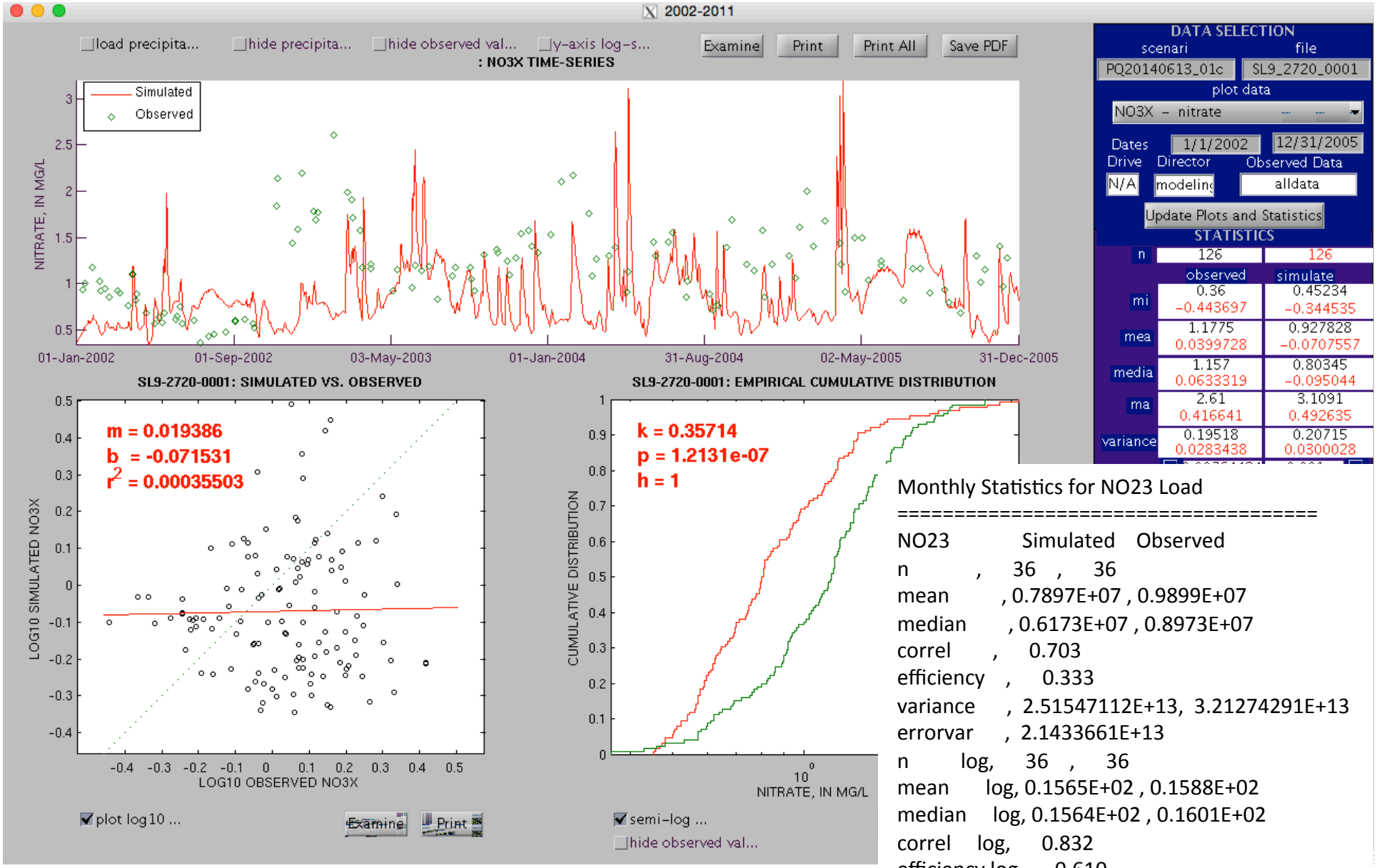
NO23	Simulated	Observed
n	36	36
mean	0.1749E+08	0.9899E+07
median	0.1332E+08	0.8973E+07
correl	0.812	
efficiency	-3.900	
variance	1.94322373E+14	3.21274291E+13
errorvar	1.57424929E+14	
n log,	36	36
mean log,	0.1616E+02	0.1588E+02
median log,	0.1640E+02	0.1601E+02
correl log,	0.917	
efficiency log,	0.185	

+01 , 0.6827E+00

nutrient simulation based on PQUAL

with revised land & river calibration

Yrs85-05 – NO3X – Susquehanna at Conowingo



Monthly Statistics for NO23 Load

==========

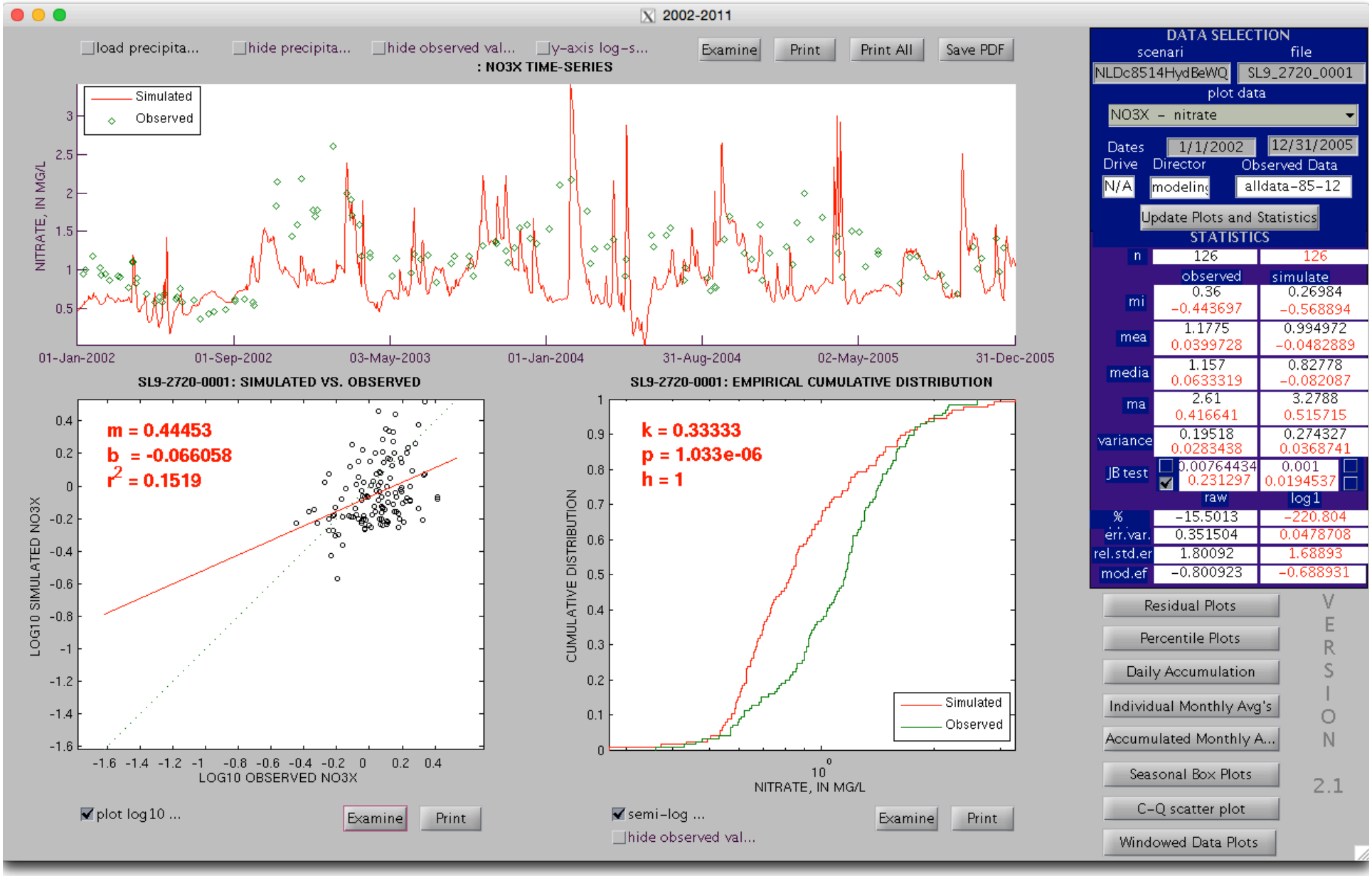
NO23	Simulated	Observed
n	36	36
mean	0.7897E+07	0.9899E+07
median	0.6173E+07	0.8973E+07
correl	0.703	
efficiency	0.333	
variance	2.51547112E+13	3.21274291E+13
errorvar	2.1433661E+13	
n log,	36	36
mean log,	0.1565E+02	0.1588E+02
median log,	0.1564E+02	0.1601E+02
correl log,	0.832	
efficiency log,	0.610	
g,	0.5798E+00	0.6827E+00
g,	0.266	

nutrient simulation based on UNECs (uncalibrated) Phase-6 Oct'2014

Mean Residence Time – Turn-over Time
(time taken for the 50% of the mass to exit/flush out of the system)

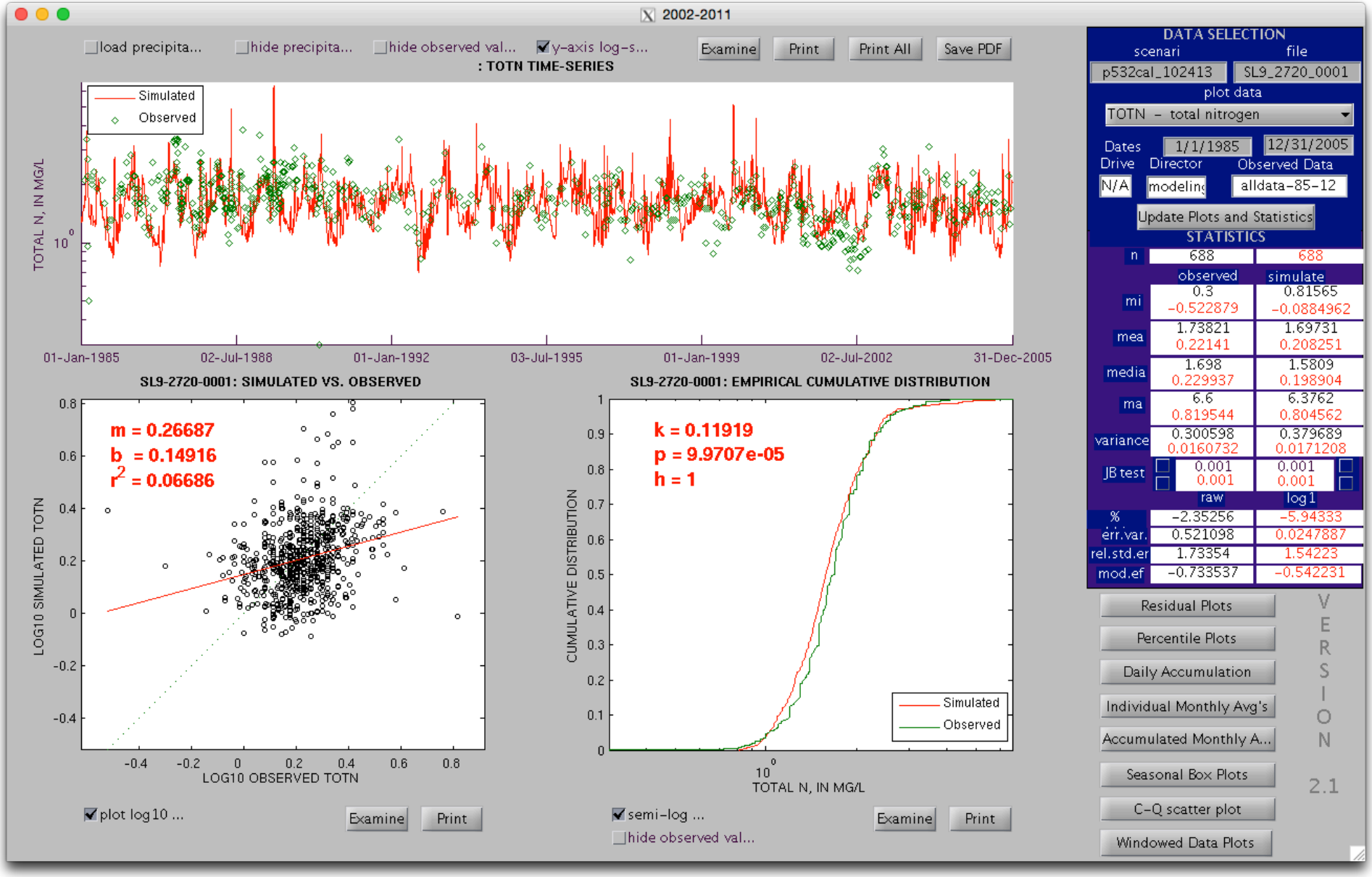
Transport	Phase 6, Oct'2014	Phase 6, Apr'2015
Surface flow	3 months	3 months
Sediment flux	4 months	4 months
Inter-flow	8 months	15 months
Groundwater flow	12 months	51 months

Yrs85-14 – NO3X – Susquehanna at Conowingo

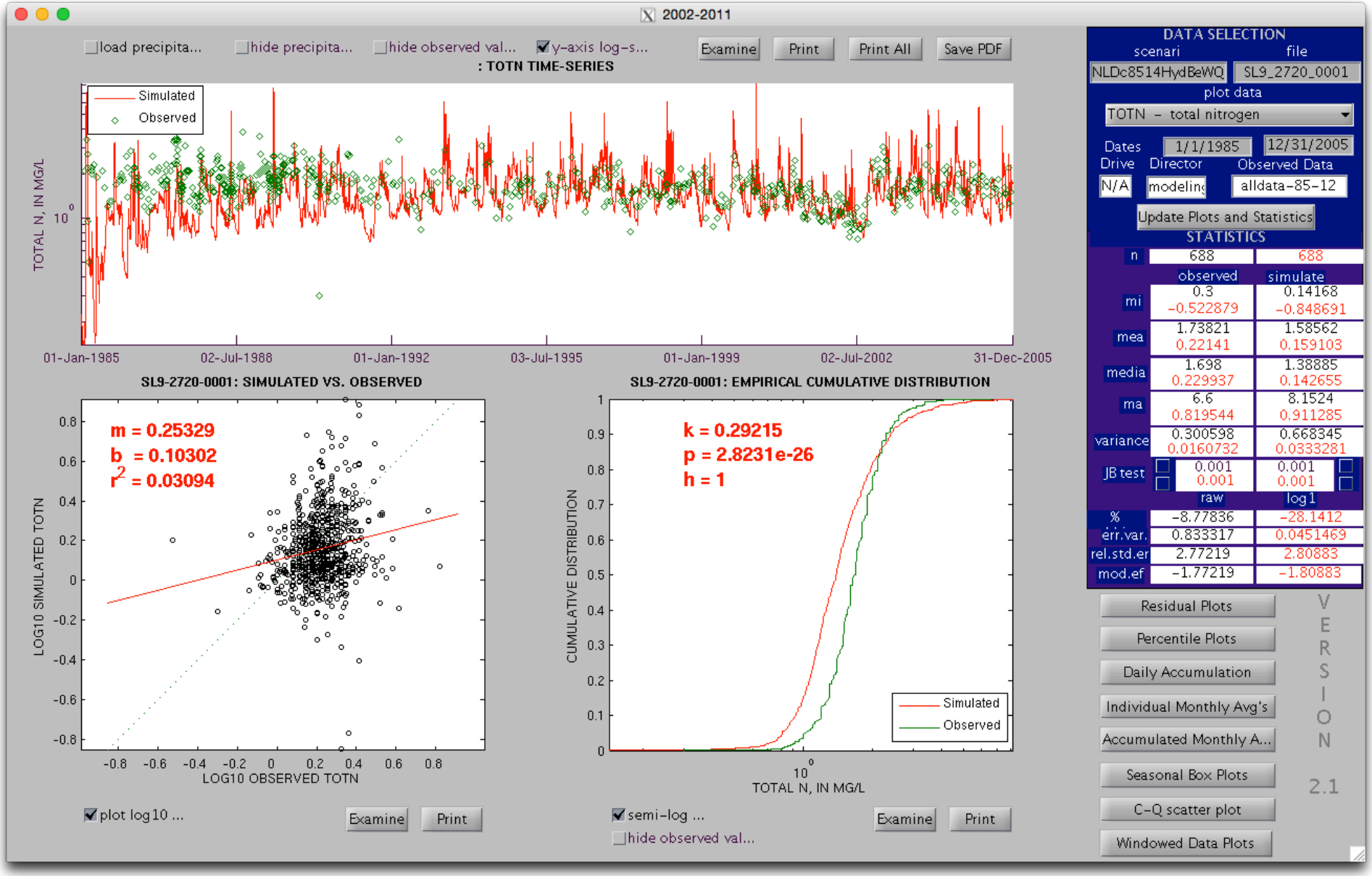


nutrient simulation based on UNECs (uncalibrated) Phase-6 Apr'2015

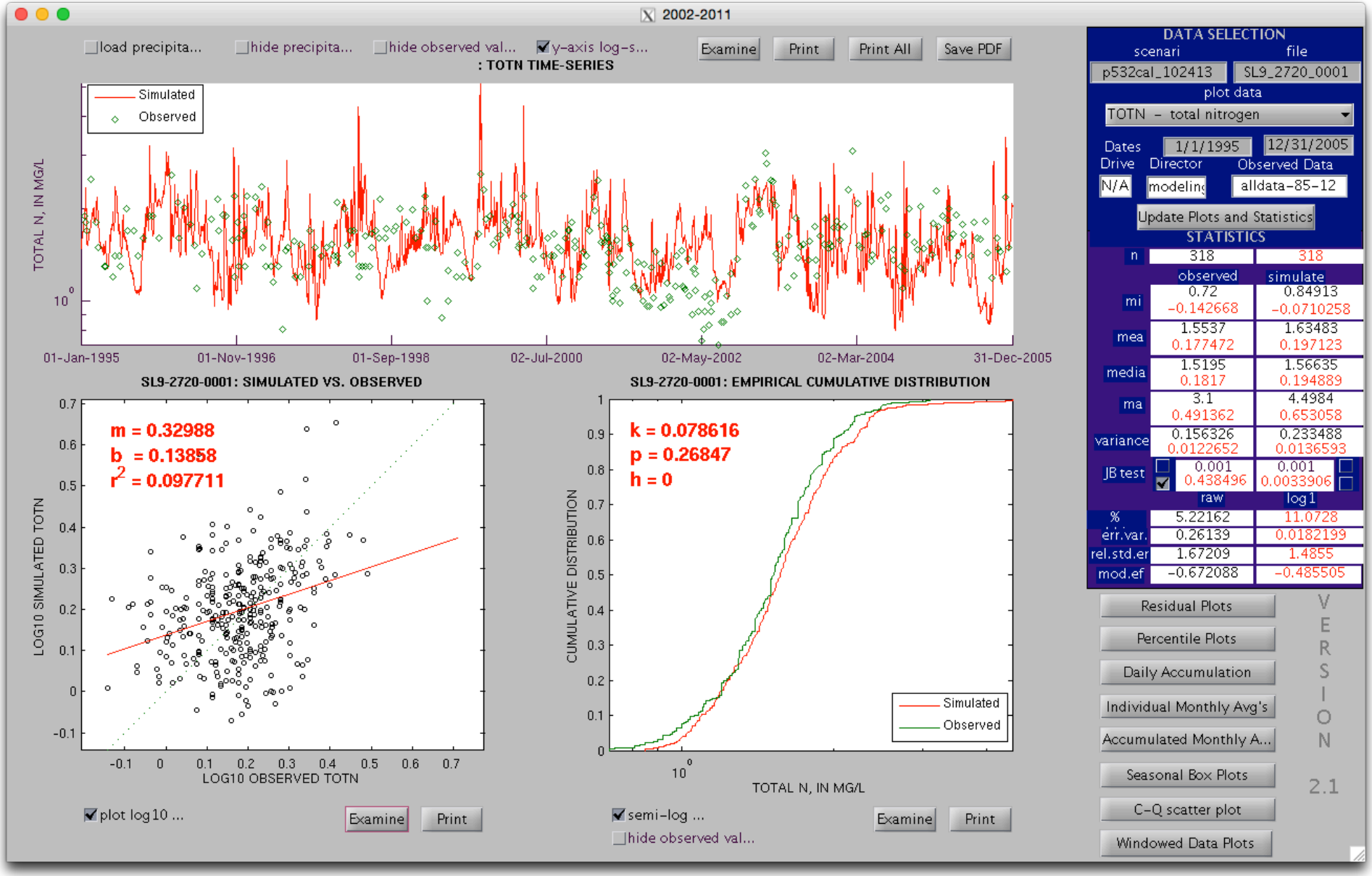
Phase 5 Model with AGCHEM/PQUAL



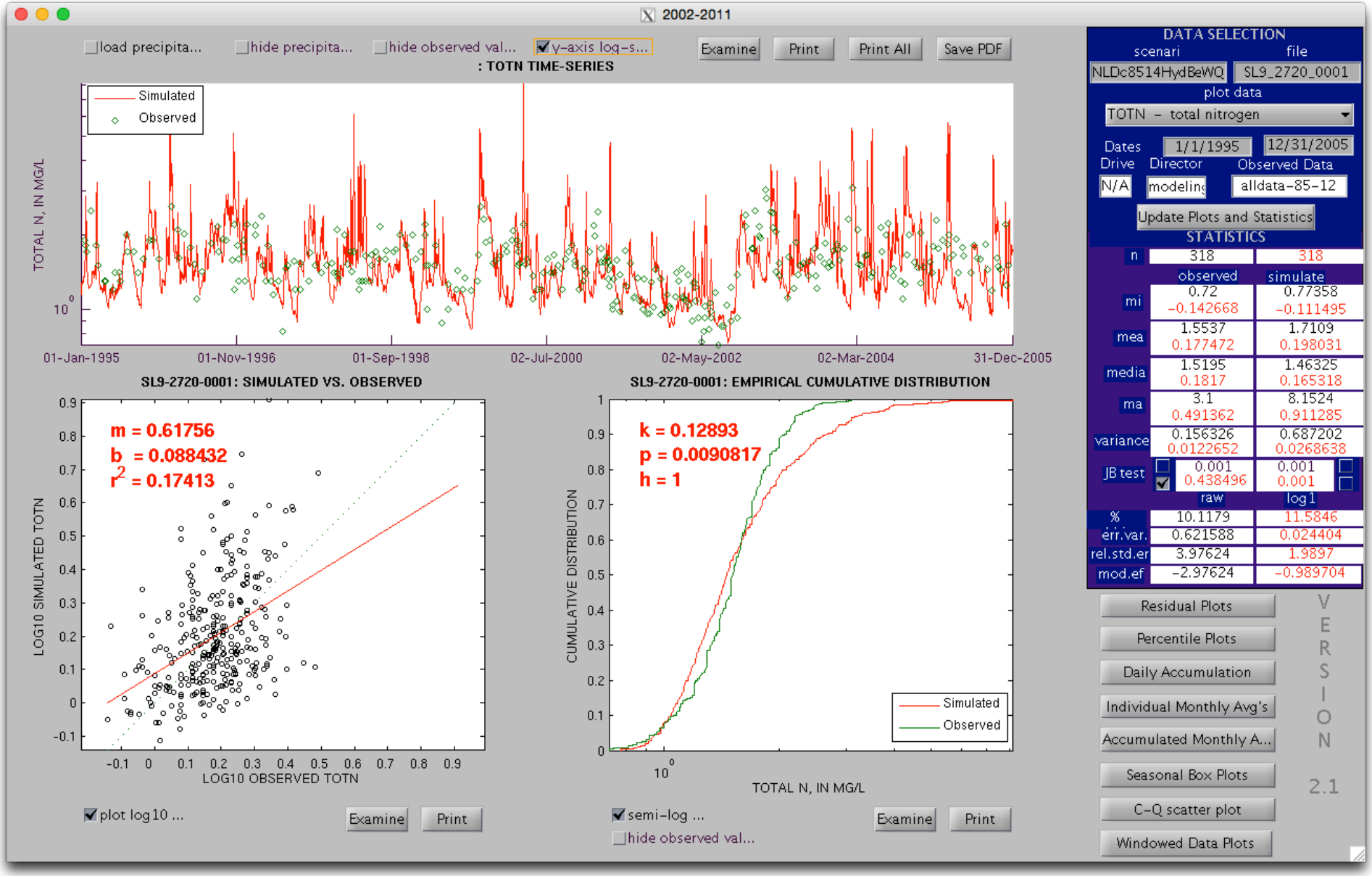
Phase 6 Model with UNEC, Apr'2015



Phase 5 Model with AGCHEM/PQUAL



Phase 6 Model with UNEC, Apr'2015

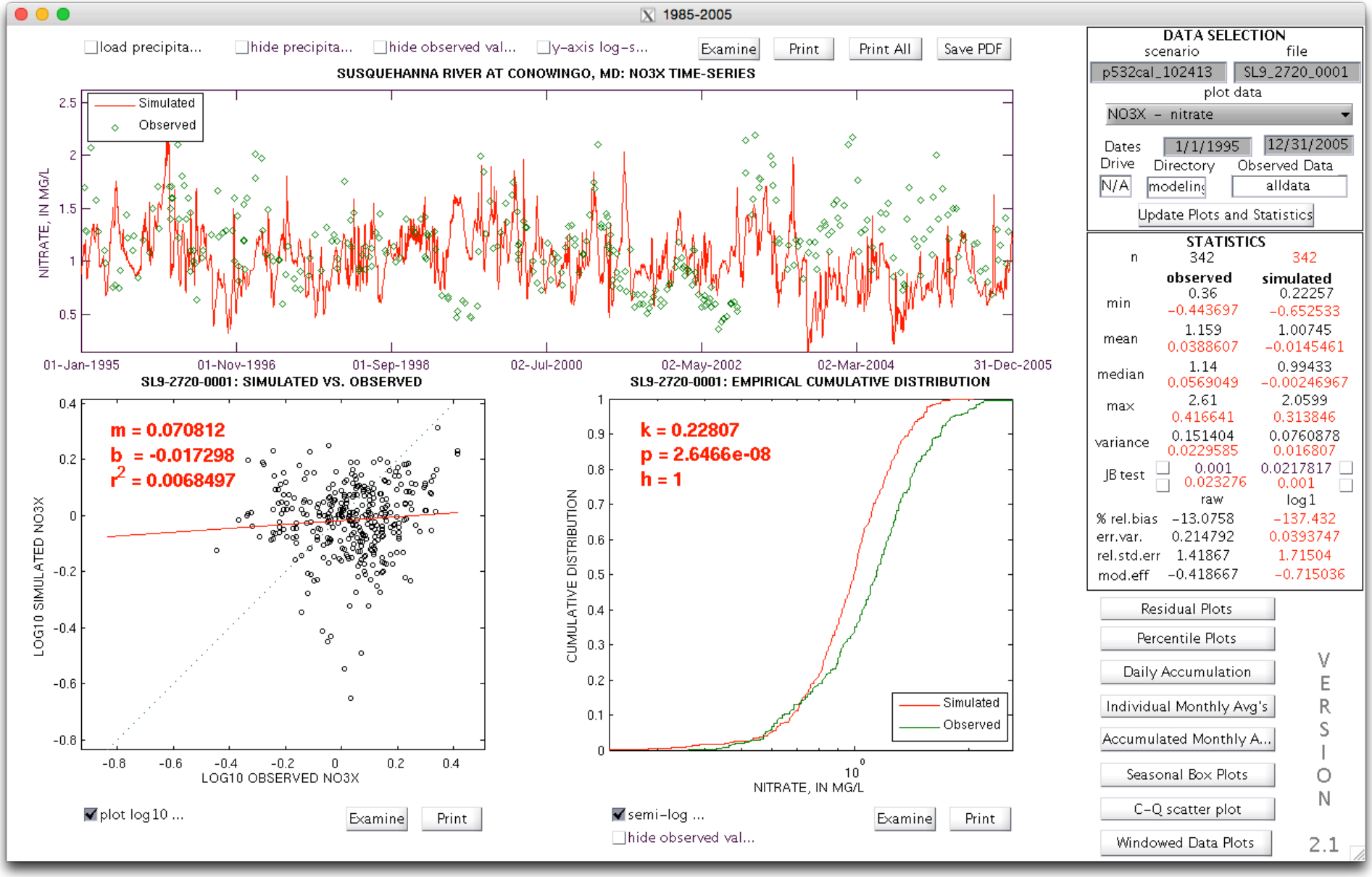


Major River Monitoring Stations

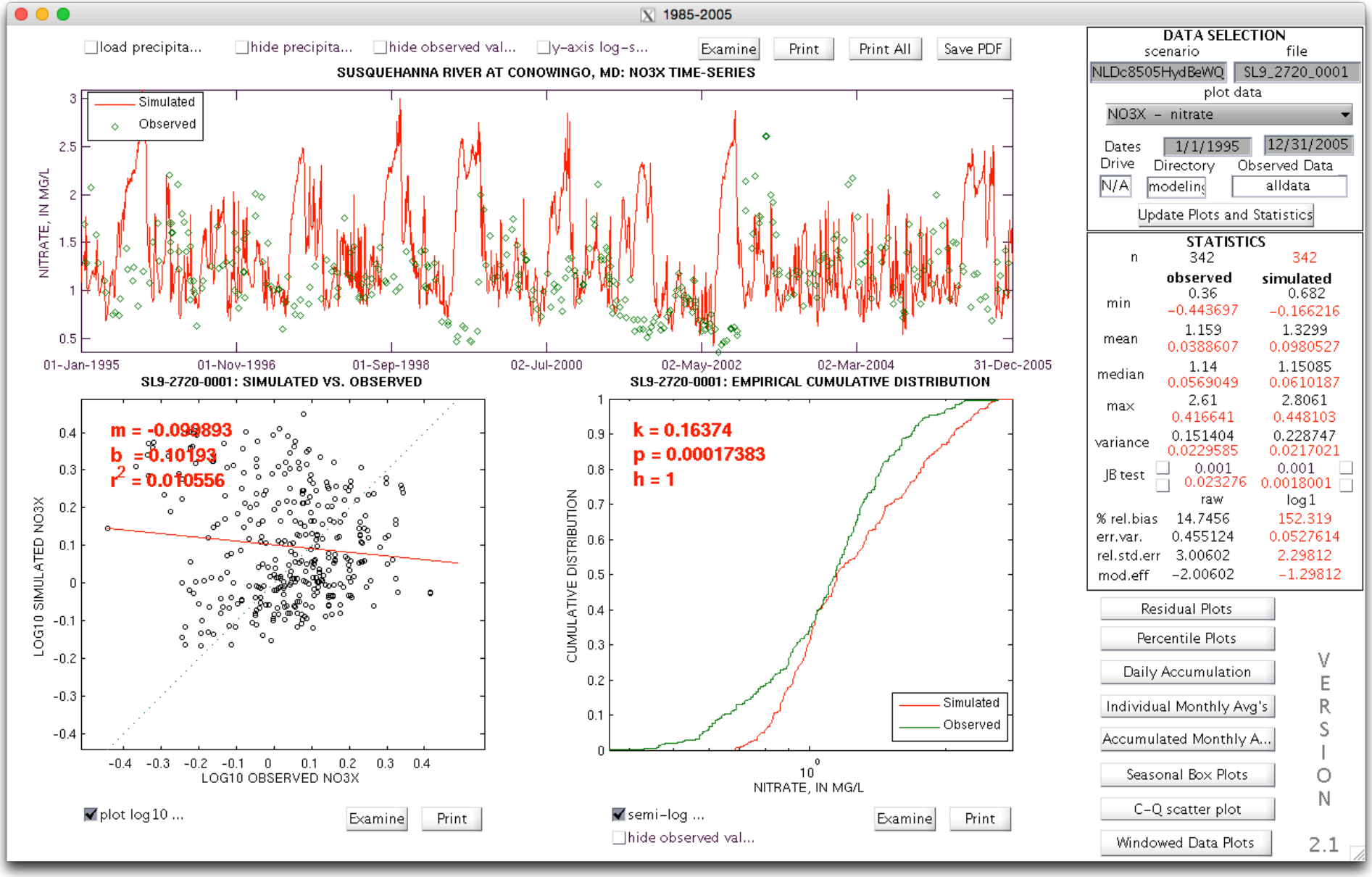
Rivers	Area (sq.mi)	Model Segment	USGS
Susquehanna River near Conowingo, MD	27100	SL9_2720_0001	01578310
Susquehann River at Marietta, PA	25990	SL9_2490_2520	01576000
Potomac River at Chain Bridge, Washington DC	11570	PM7_4820_0001	01646580
James River & Kanawha Canal near Richmond, VA	6753	JL7_6800_7070	02037500
Rappahannock River near Fredericksburg, VA	1595	RU5_6030_0001	01668000
Appomattox River at Matoaca, VA	1342	JA5_7480_0001	02041650
Pamunkey River near Hanover, VA	1078	YP4_6720_6750	01673000
Mattaponi River near Beulahville, VA	603	YM4_6620_0003	01674500
Patuxent River at Bowie, MD	348	XU3_4650_0001	01594440
Choptank River near Greensboro, MD	113	EM2_3980_0001	01491000

Susquehanna River near Conowingo, MD

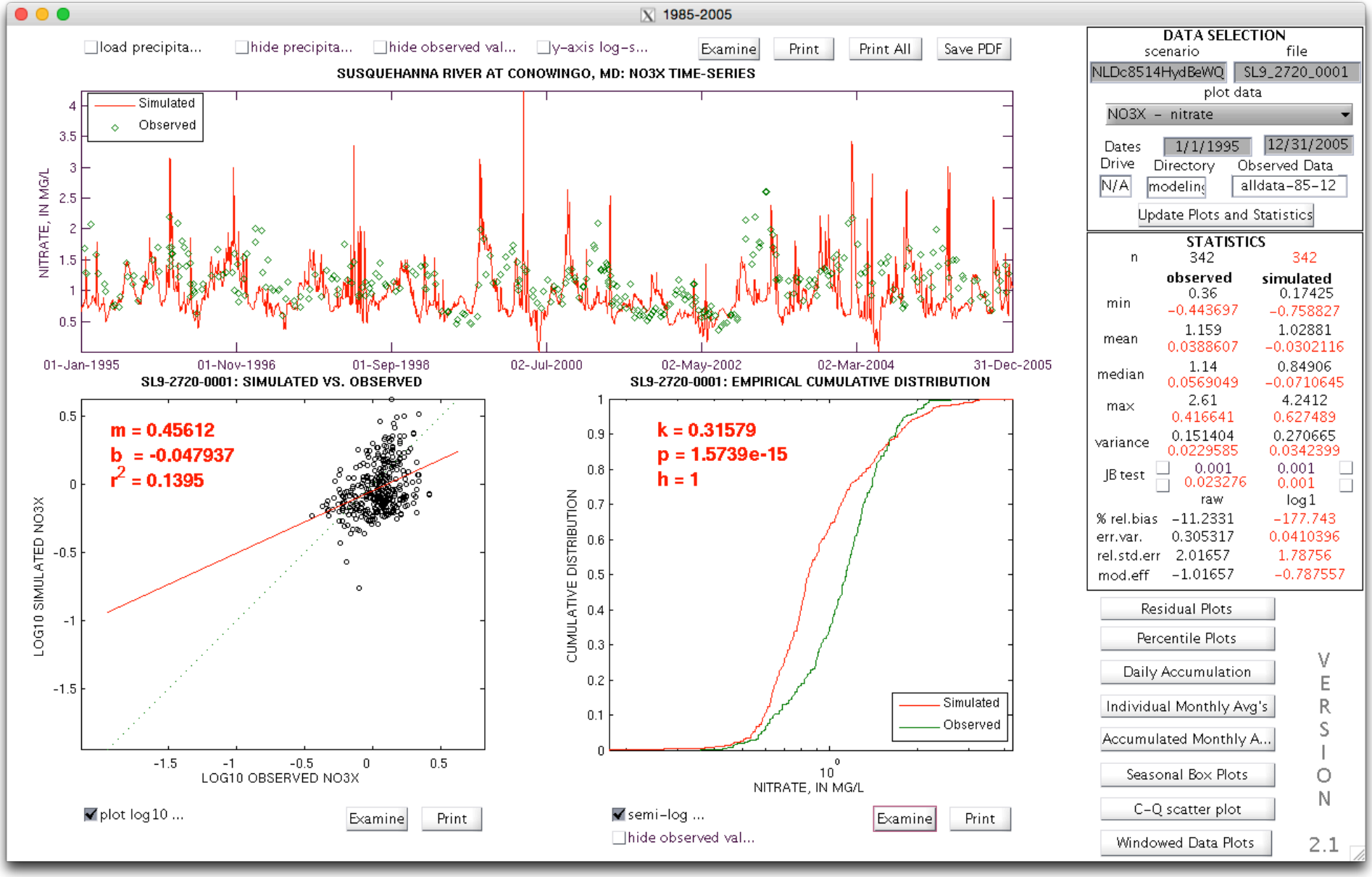
Phase 5, Nitrate, Susquehanna at Conowingo



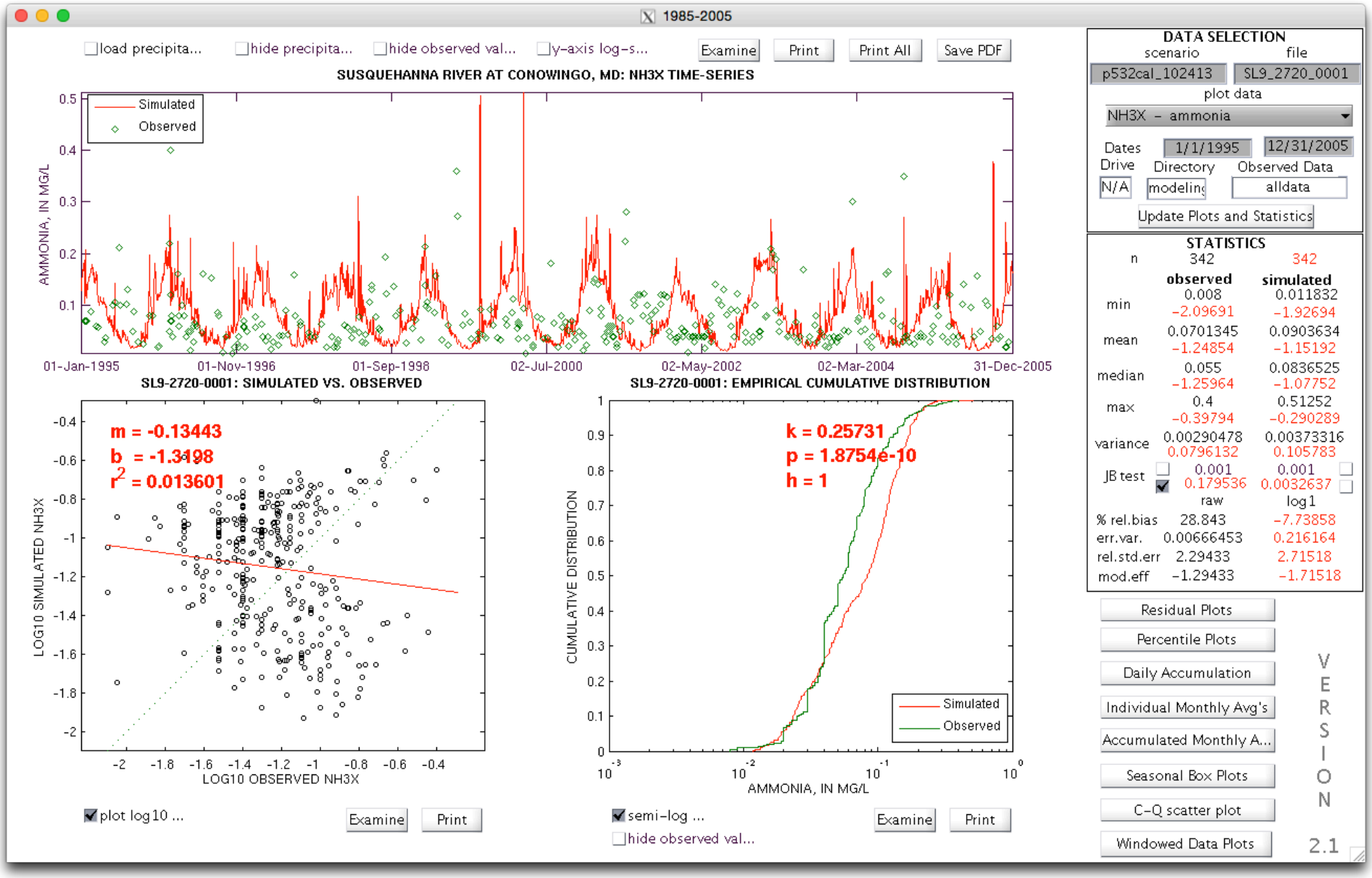
Phase 6 Oct'14, Nitrate, Susquehanna at Conowingo



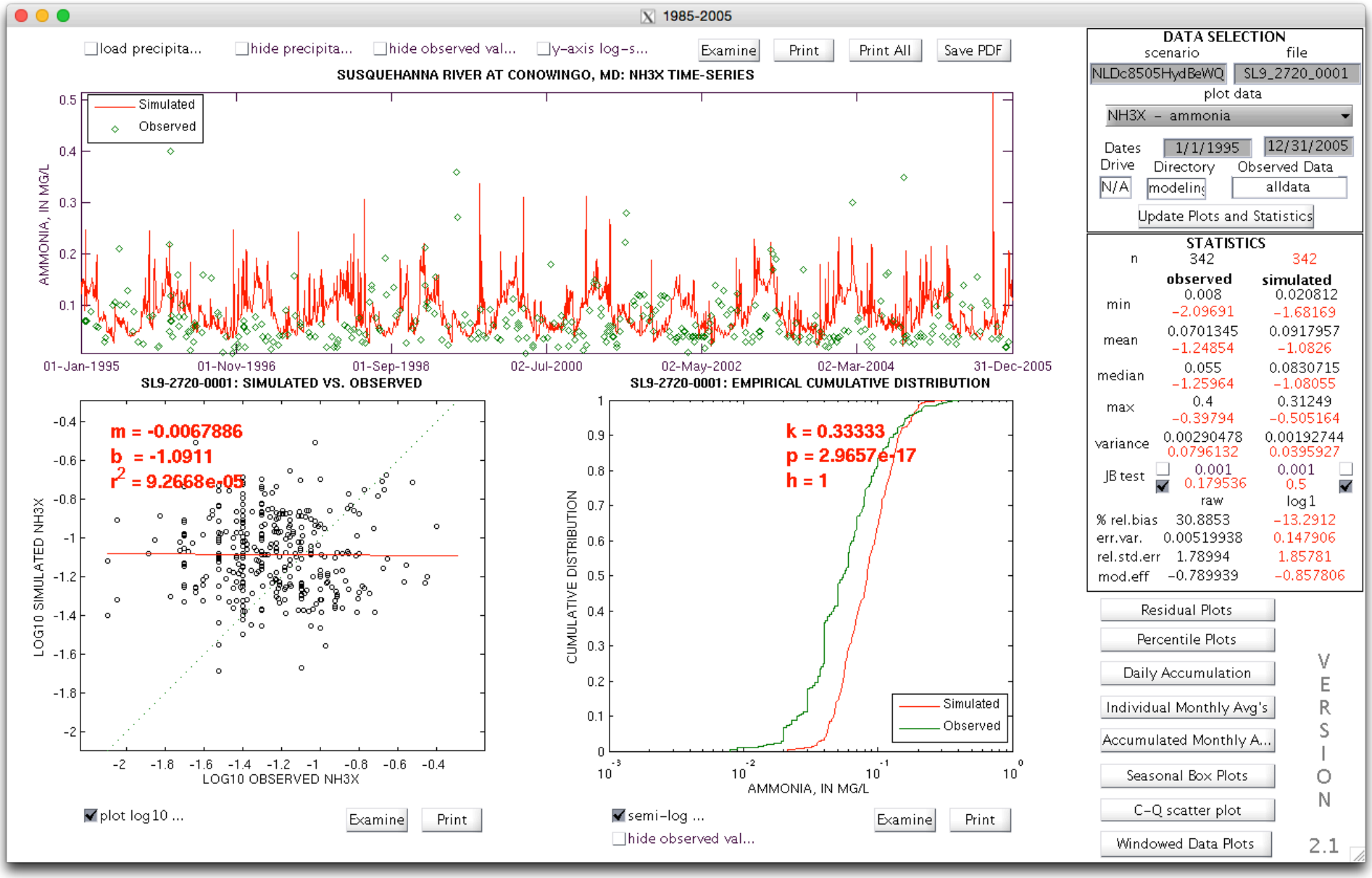
Phase 6 Apr'15, Nitrate, Susquehanna at Conowingo



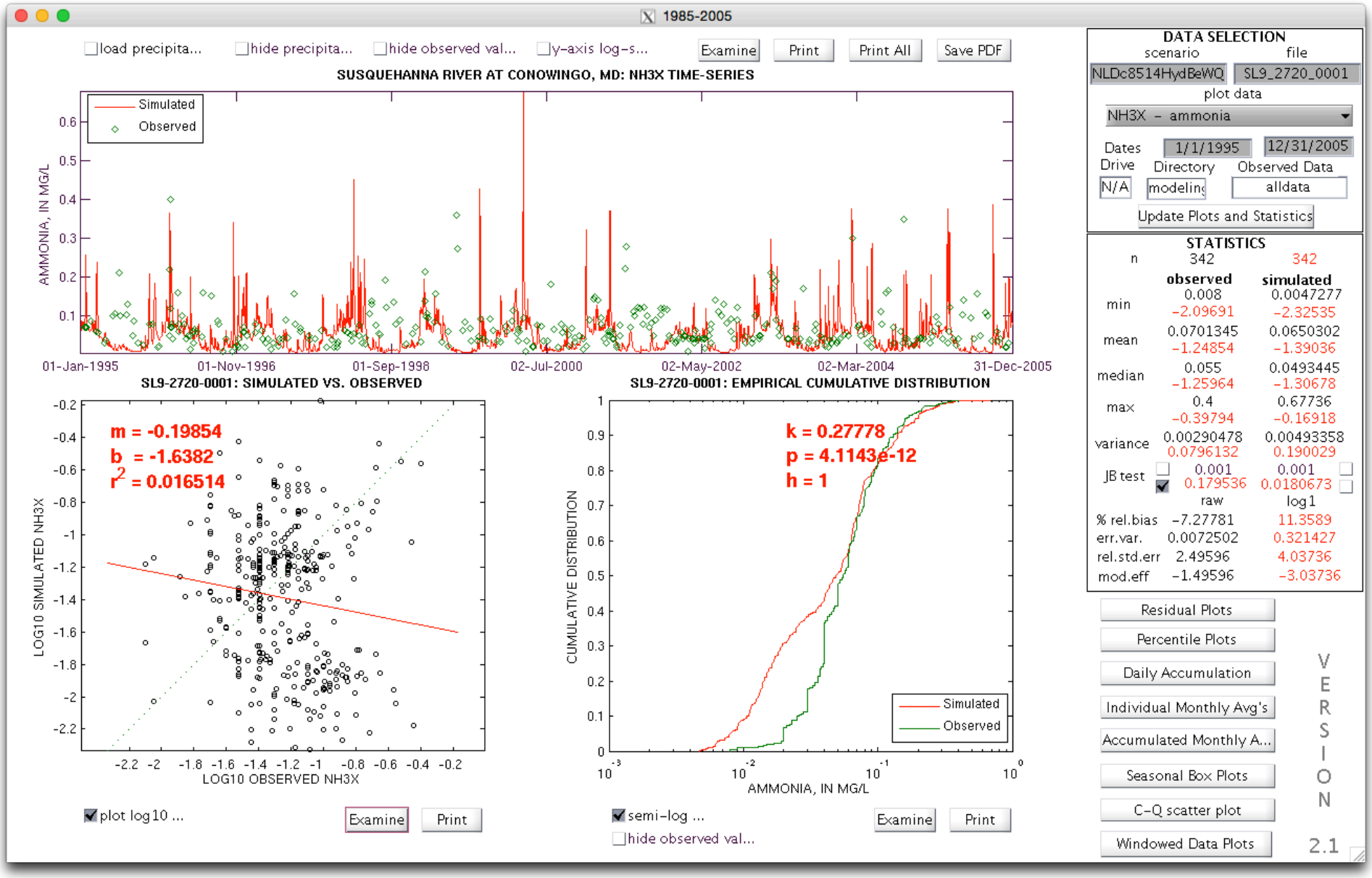
Phase 5, Ammonia, Susquehanna at Conowingo



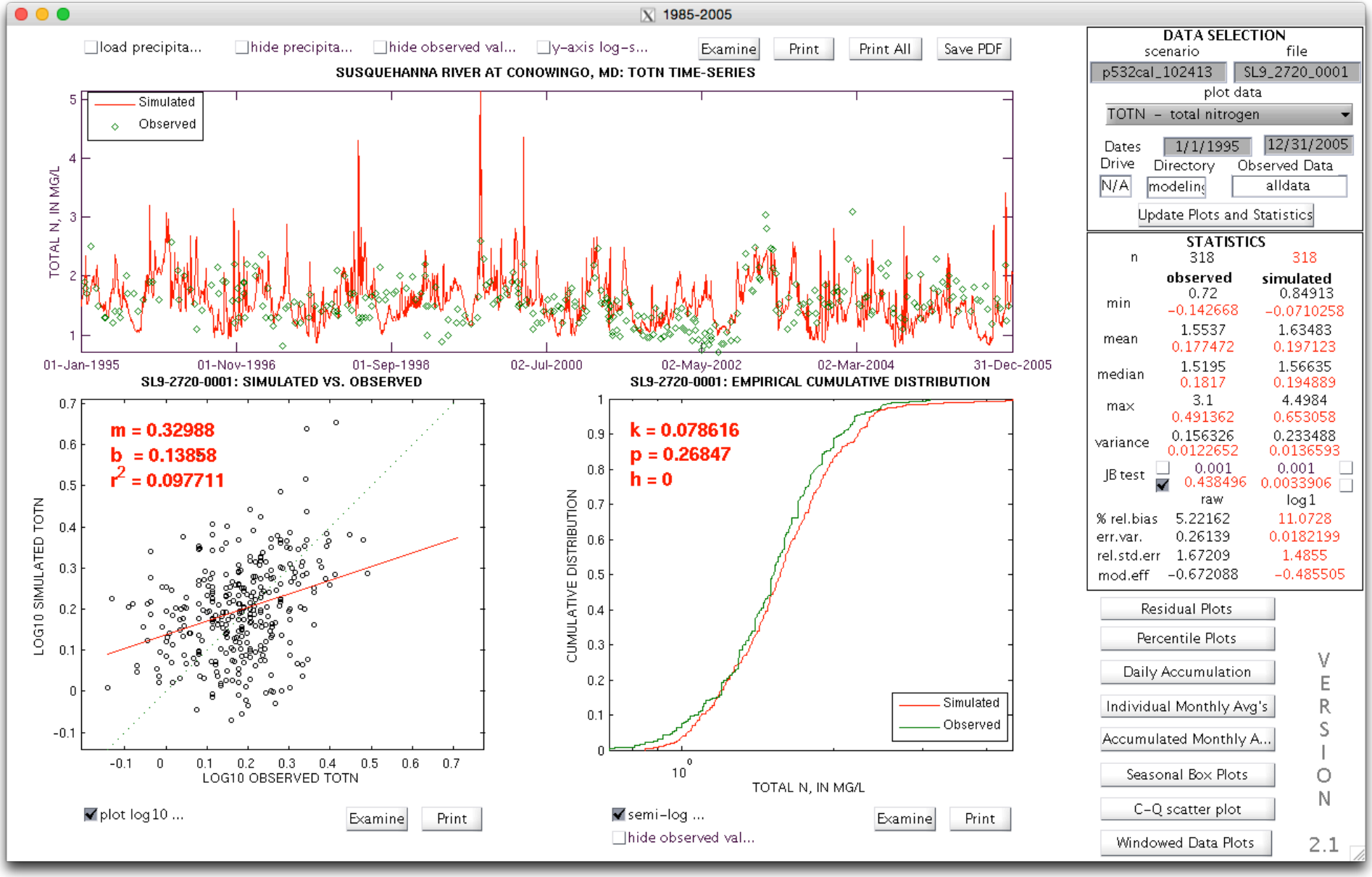
Phase 6 Oct'14, Ammonia, Susquehanna at Conowingo



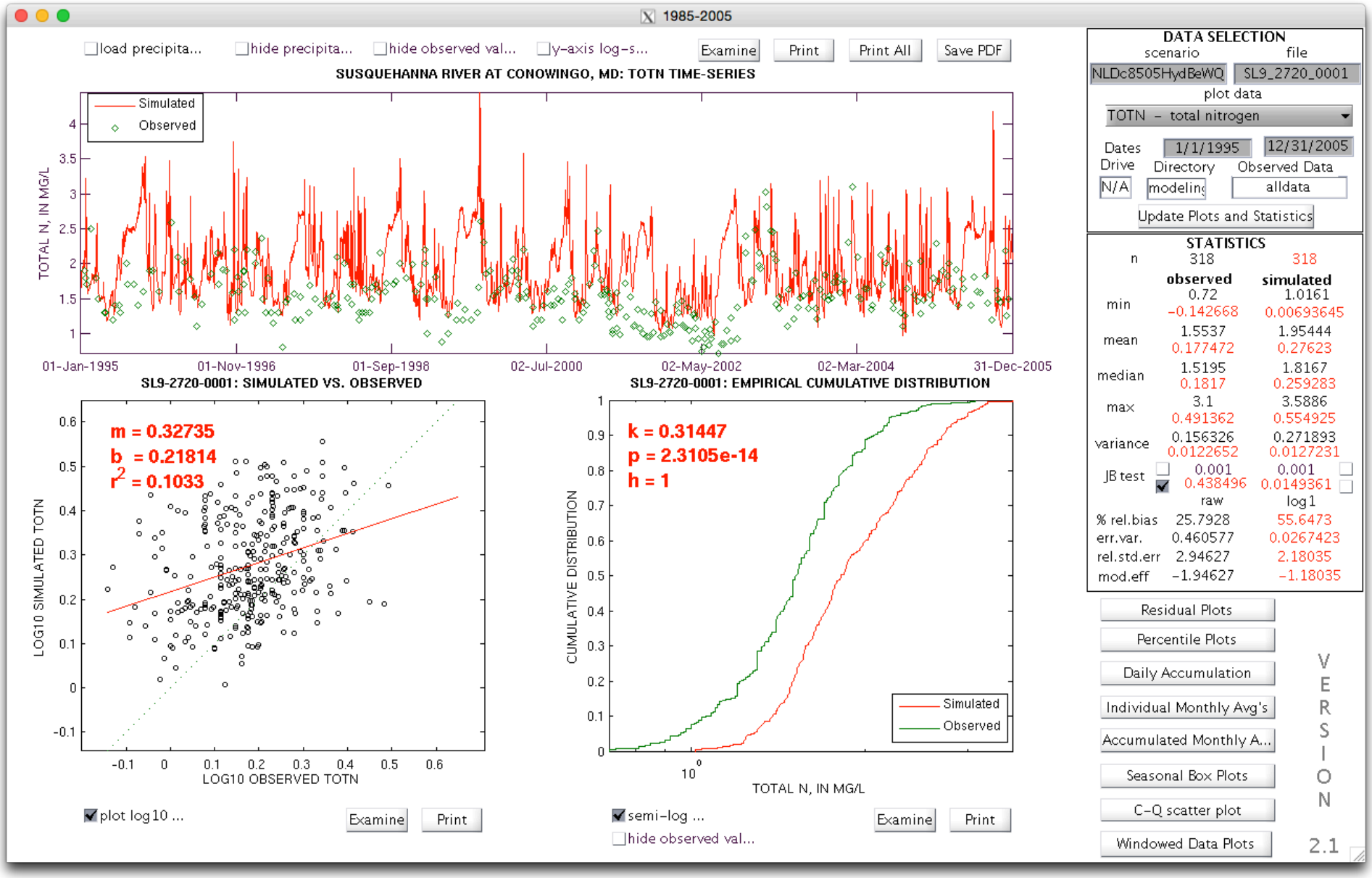
Phase 6 Apr'15, Ammonia, Susquehanna at Conowingo



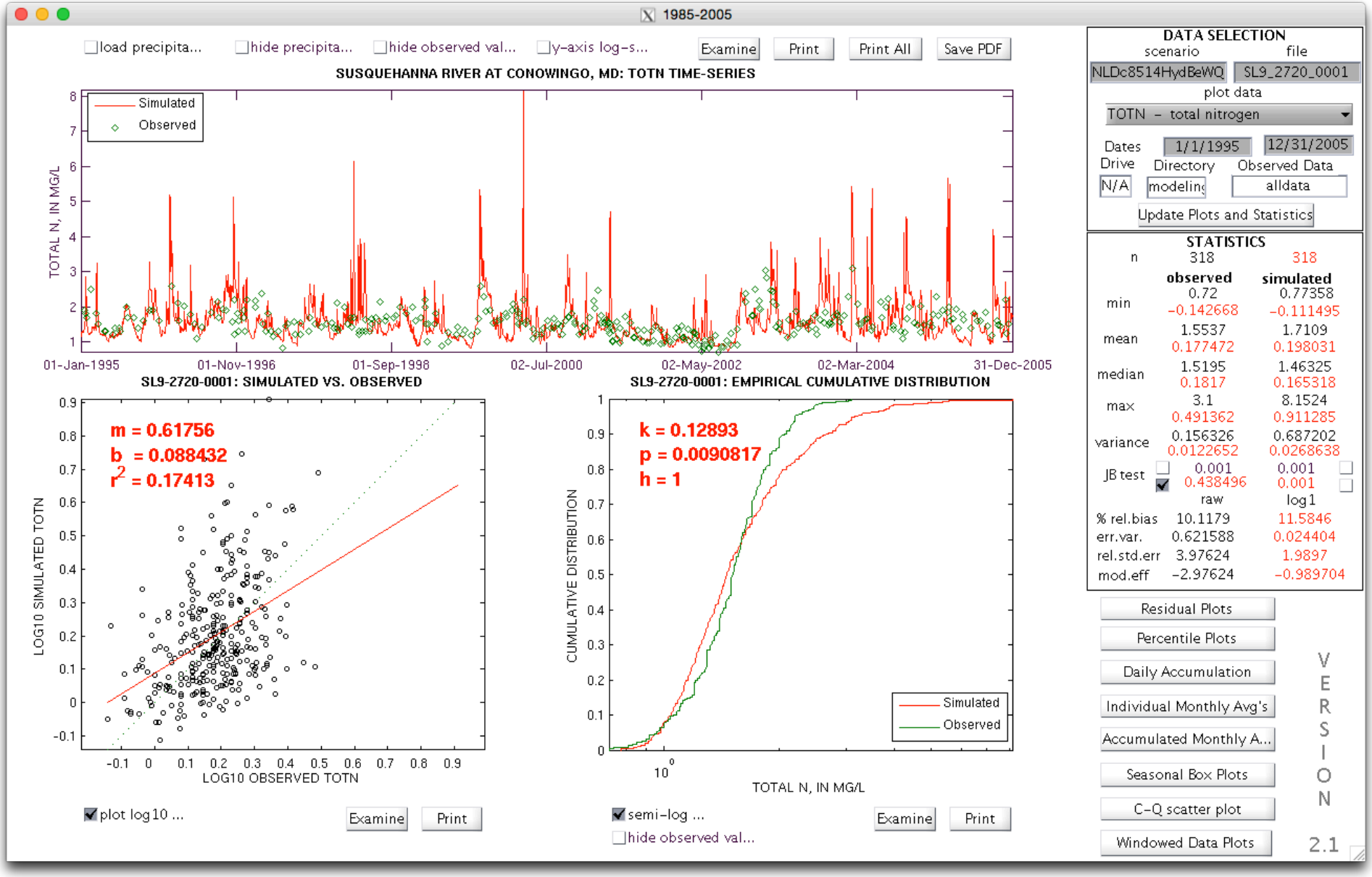
Phase 5, Nitrogen, Susquehanna at Conowingo



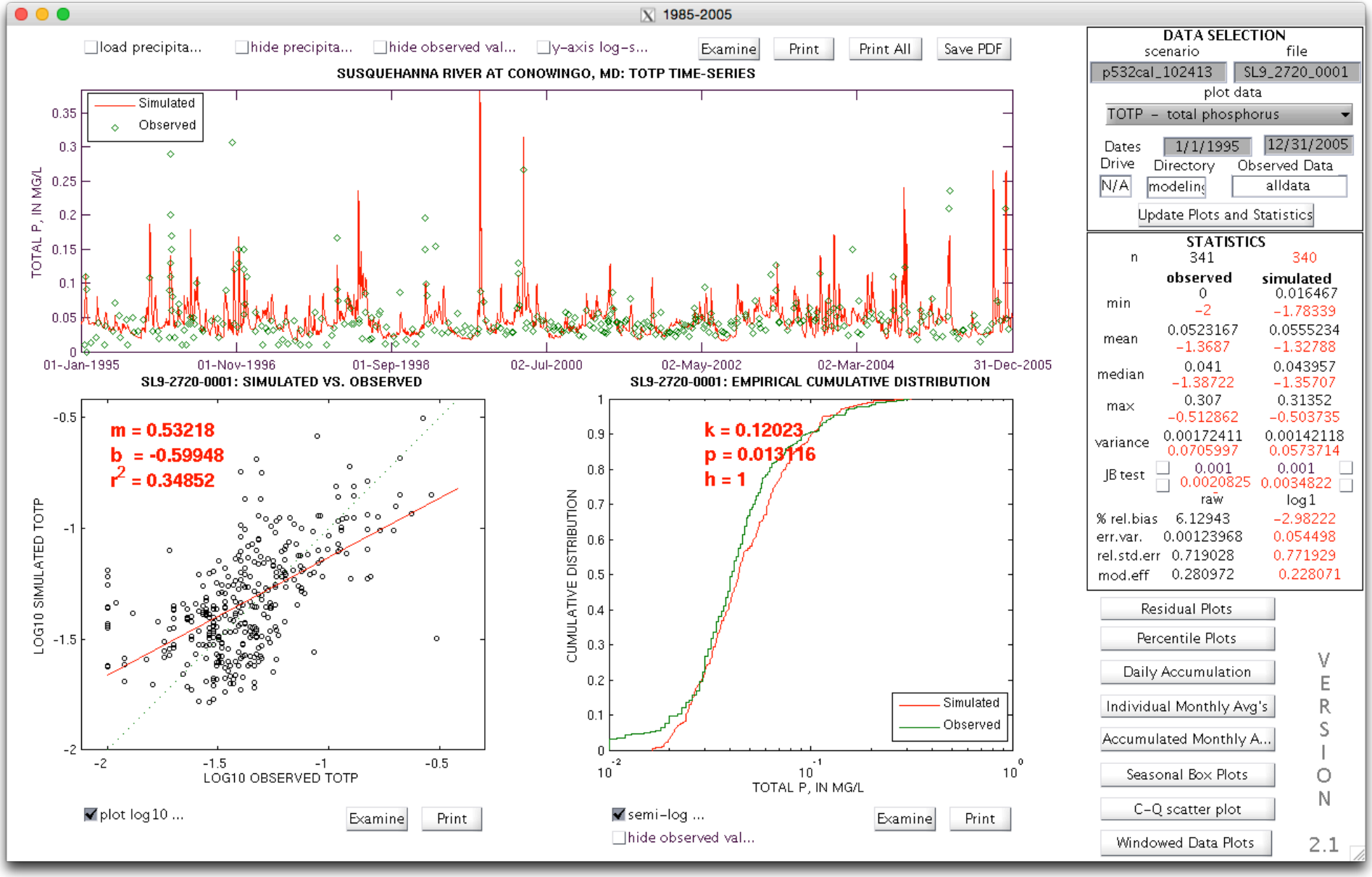
Phase 6 Oct'14, Nitrogen, Susquehanna at Conowingo



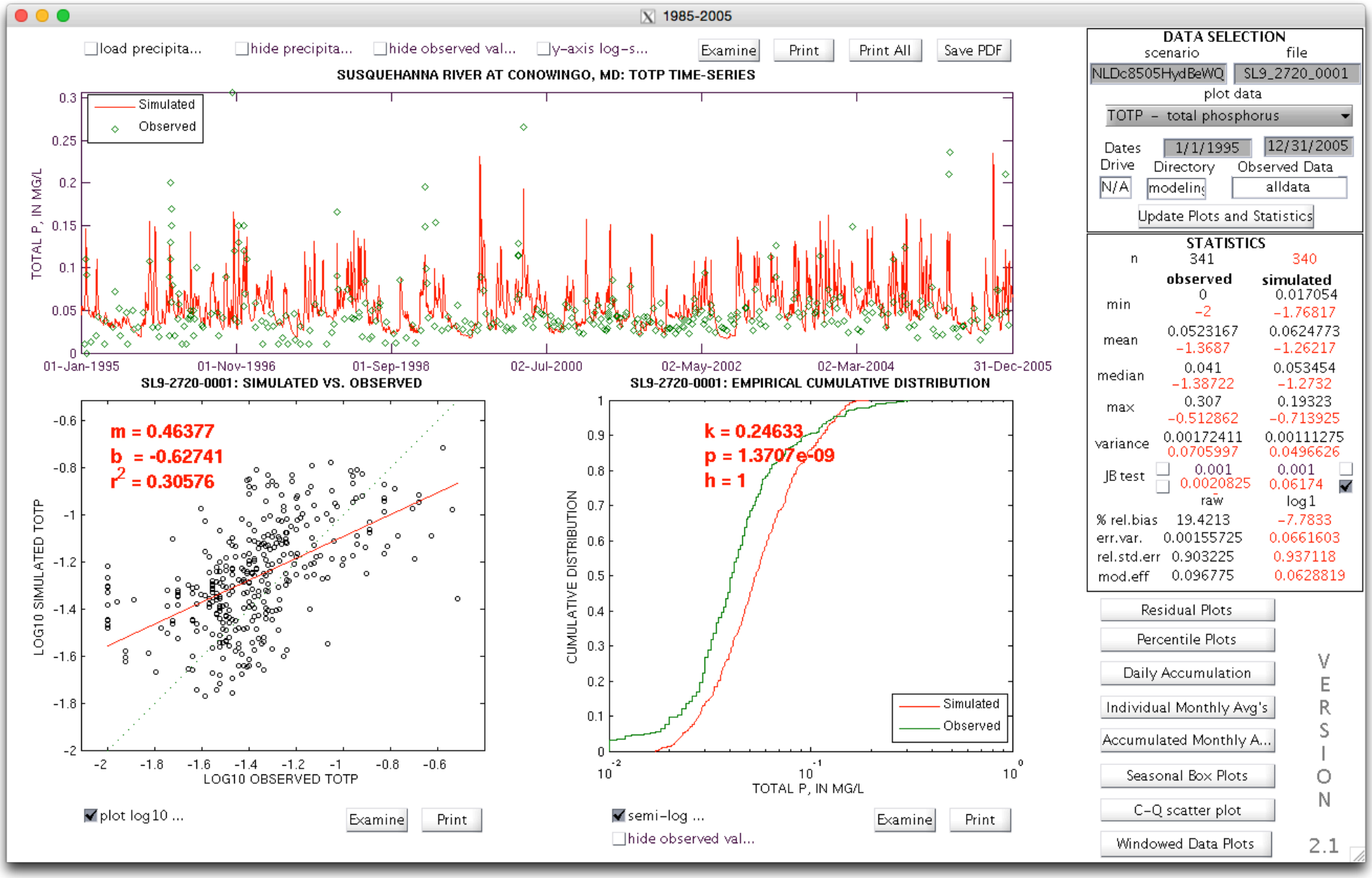
Phase 6 Apr'15, Nitrogen, Susquehanna at Conowingo



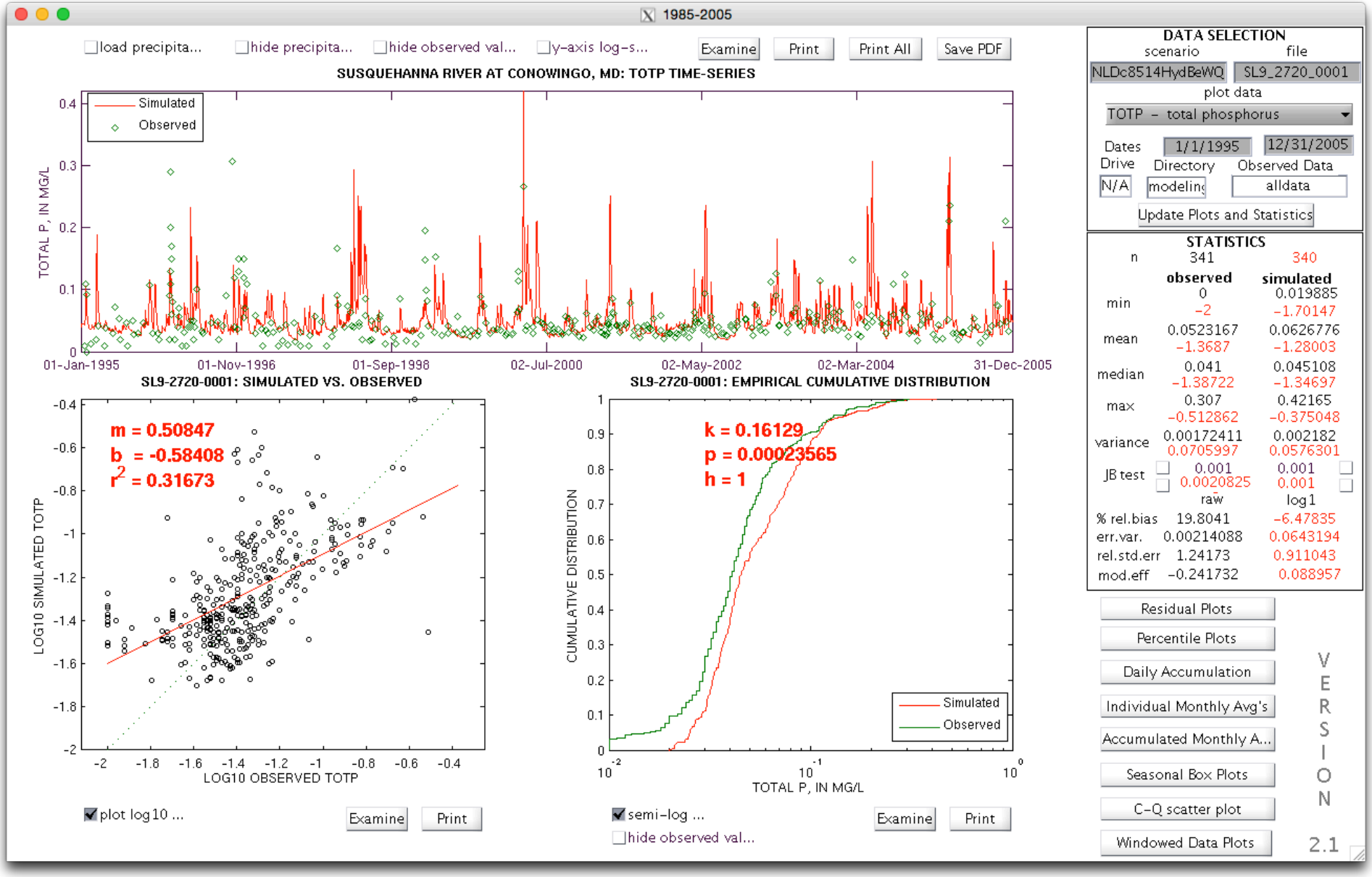
Phase 5, Phosphorous, Susquehanna at Conowingo



Phase 6 Oct'14, Phosphorous, Susquehanna at Conowingo

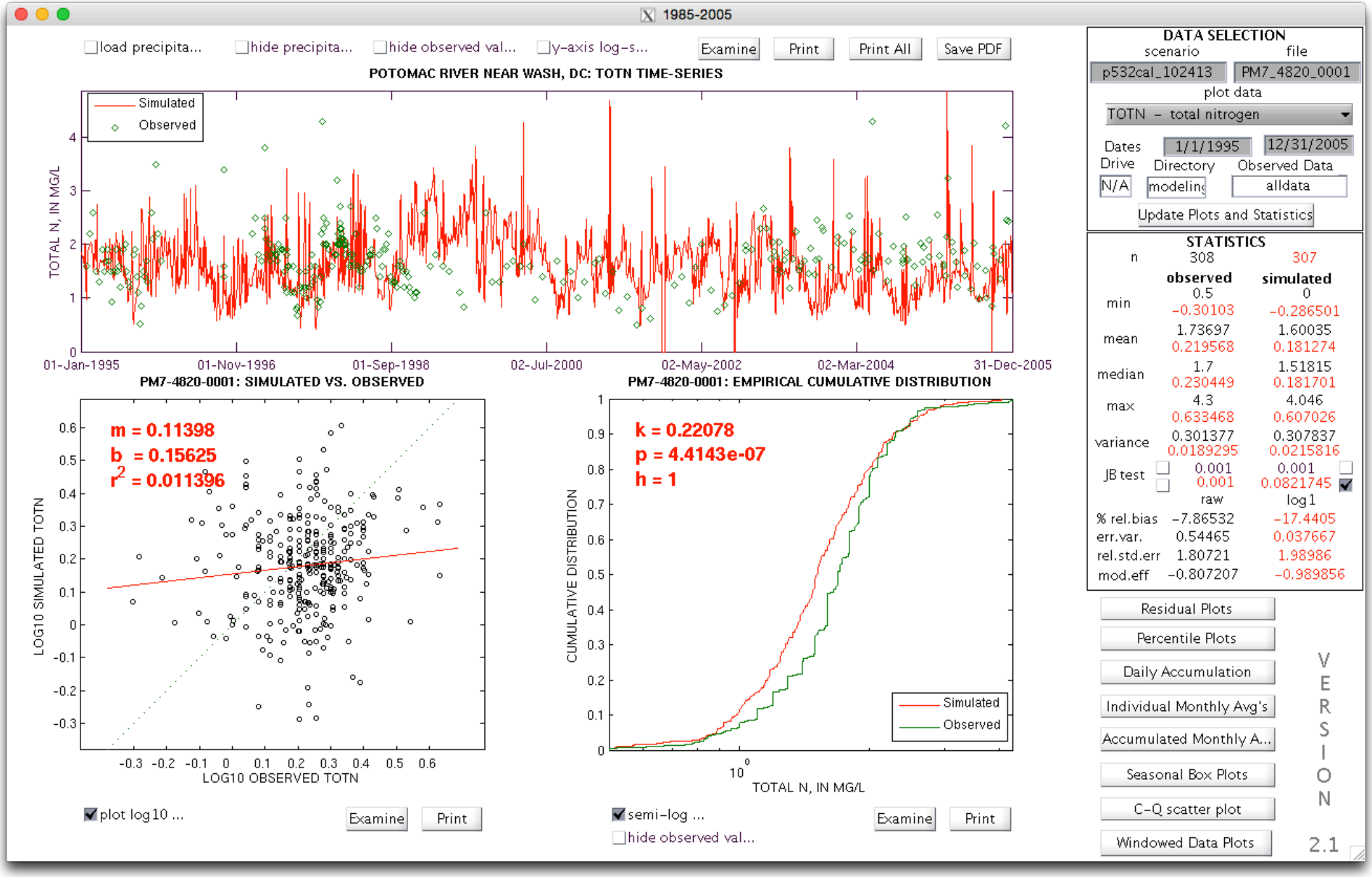


Phase 6 Apr'15, Phosphorous, Susquehanna at Conowingo

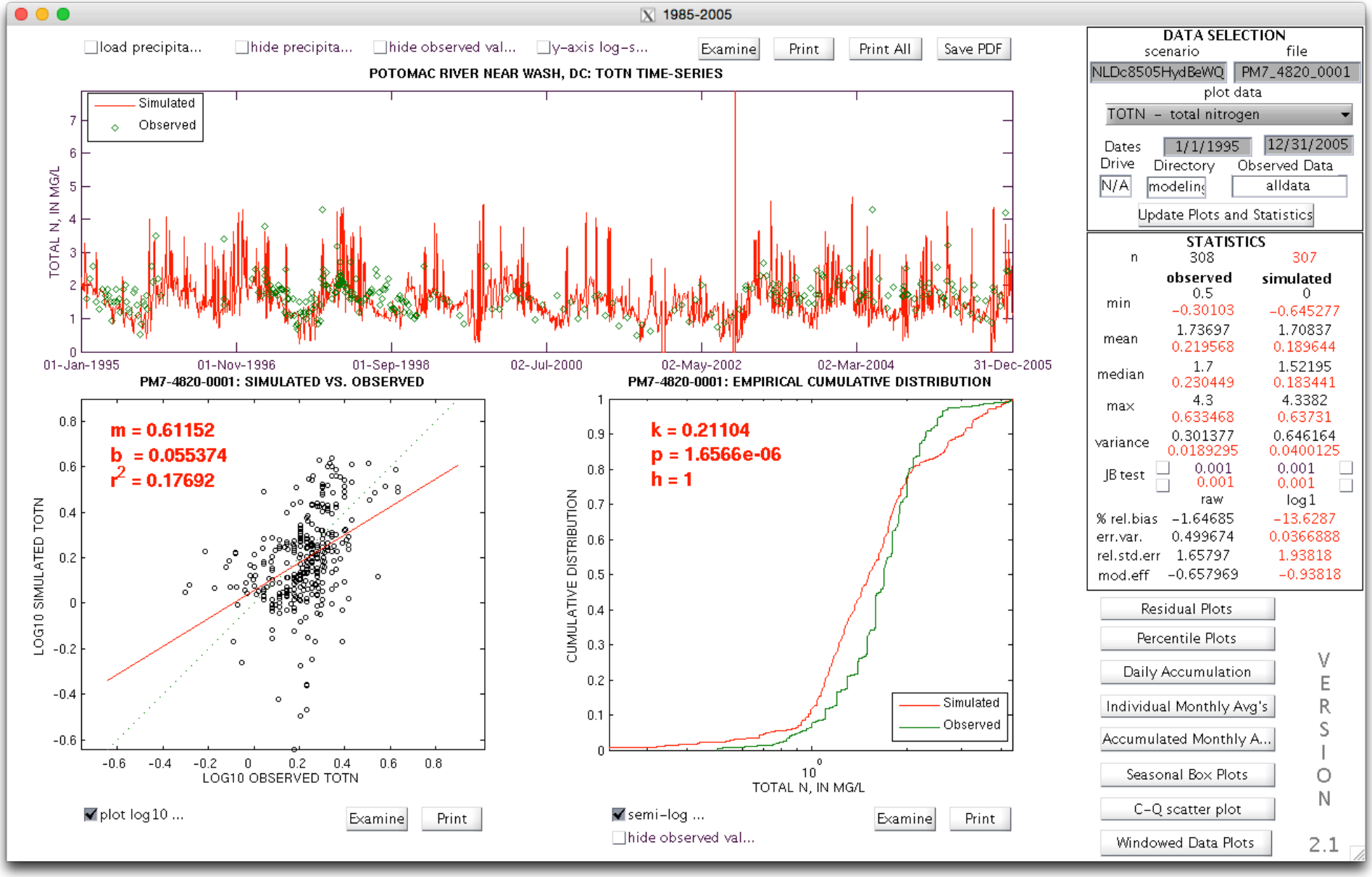


Potomac River at Chain Bridge, Washington DC

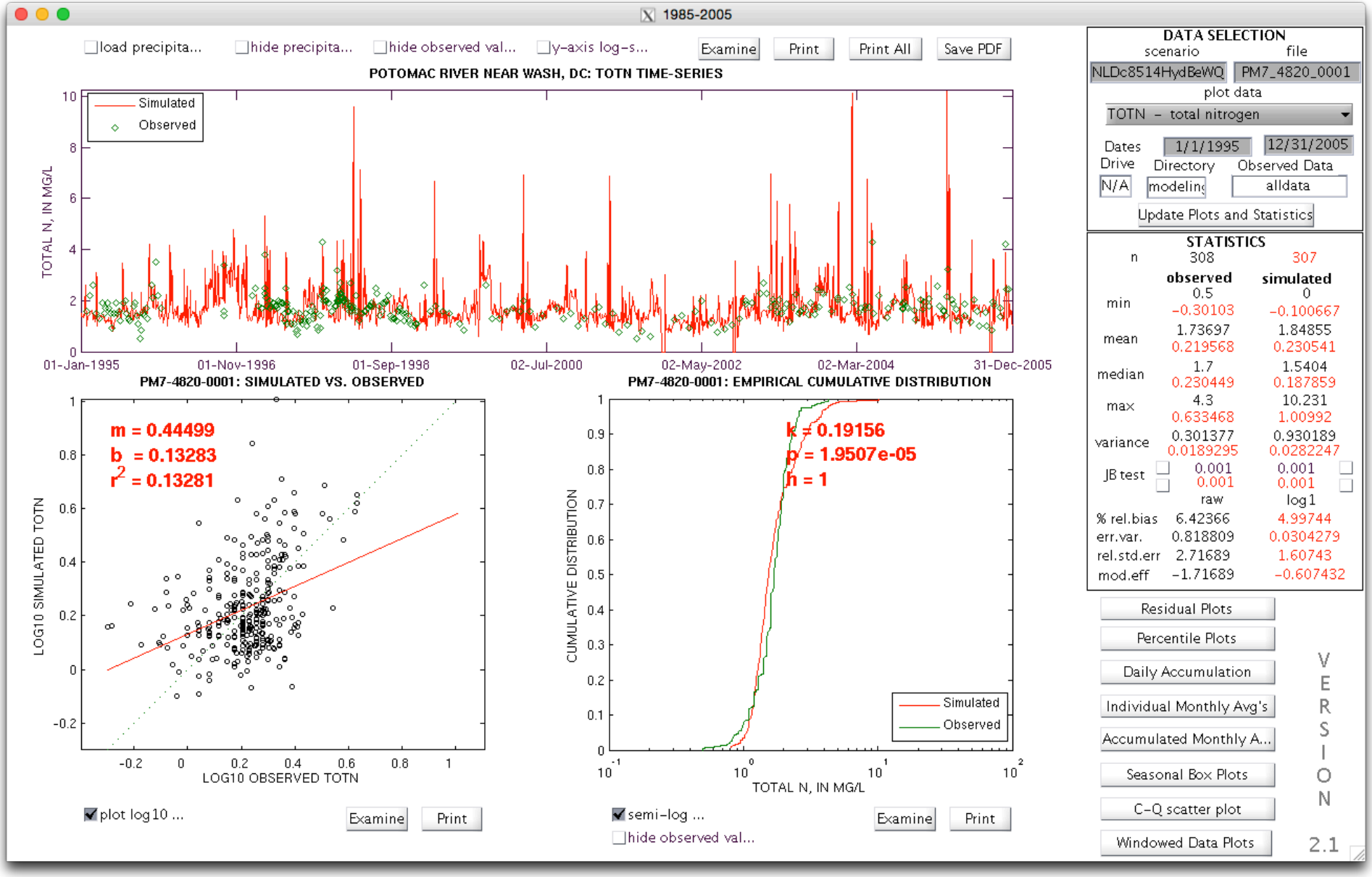
Phase 5, Nitrogen, Potomac at Chain Bridge



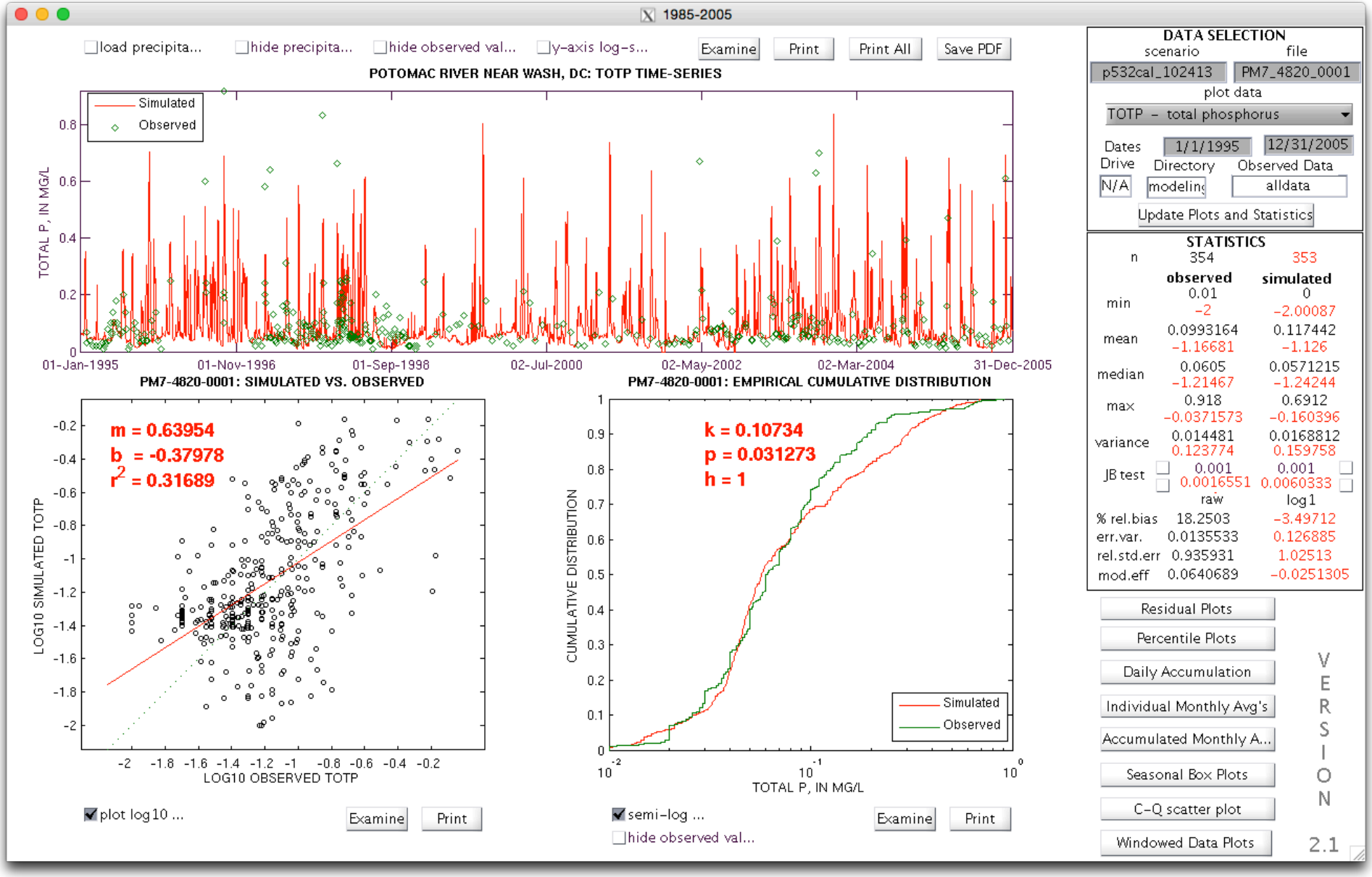
Phase 6 Oct'14, Nitrogen, Potomac at Chain Bridge



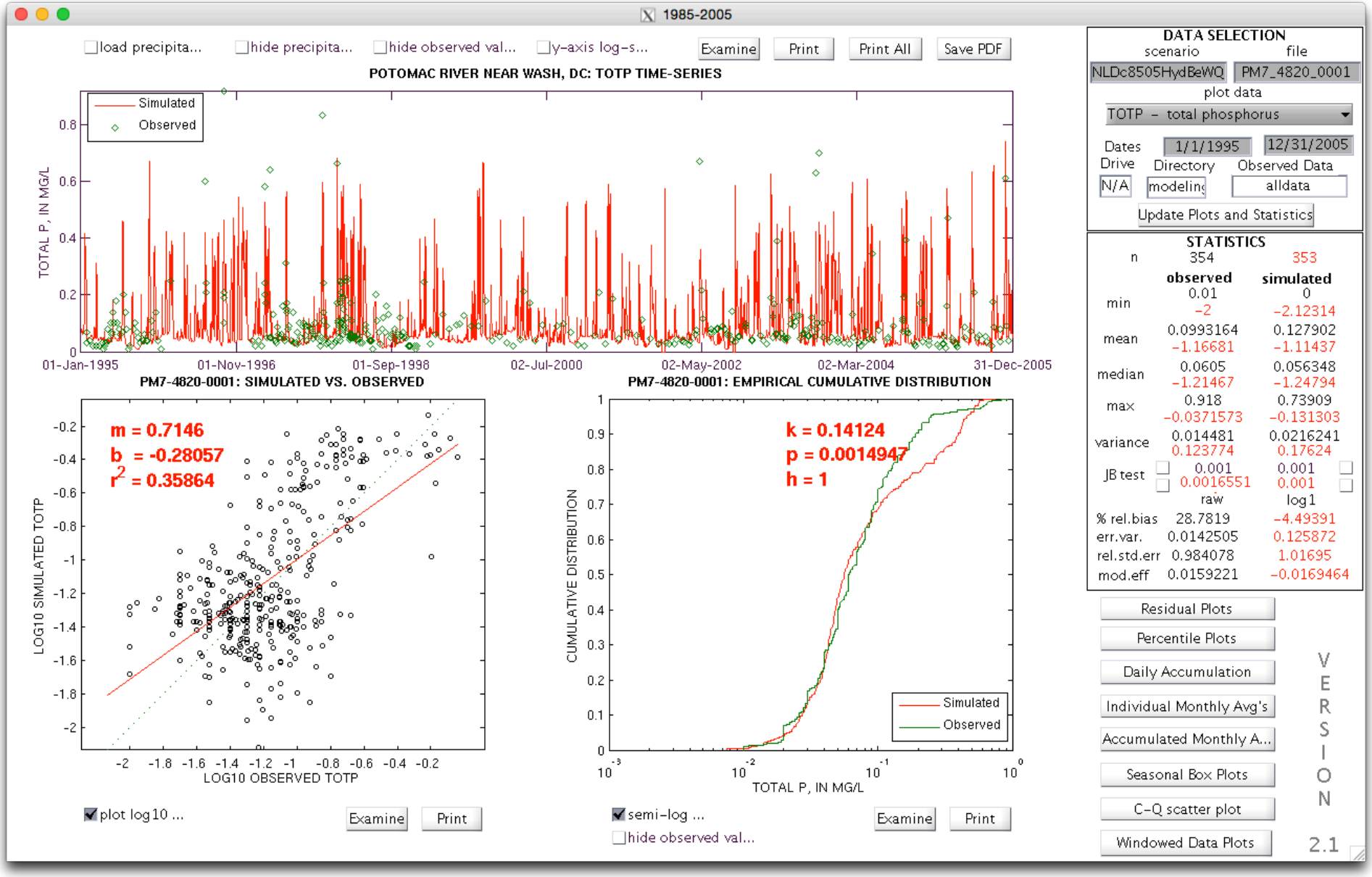
Phase 6 Apr'15, Nitrogen, Potomac at Chain Bridge



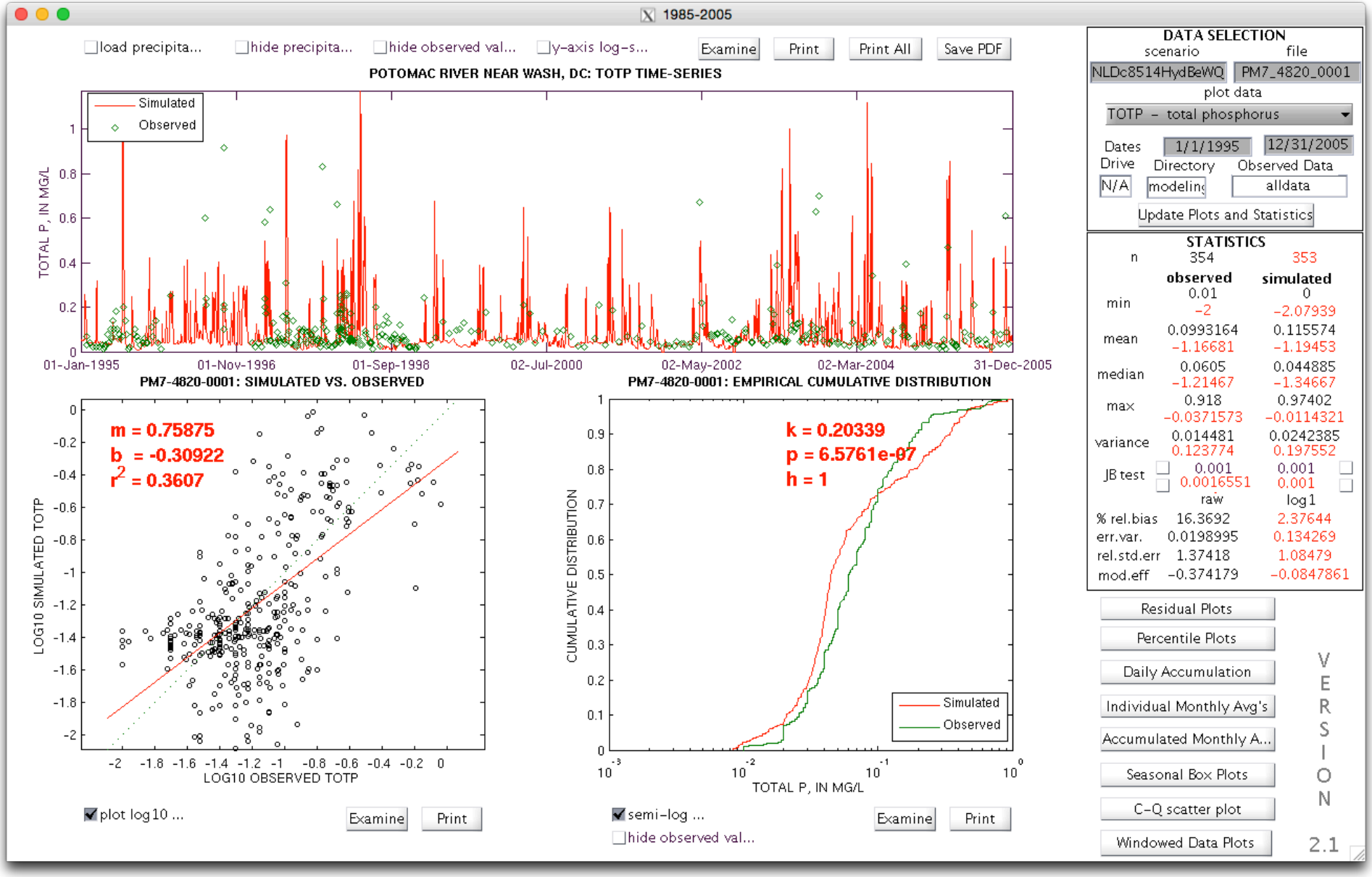
Phase 5, Phosphorous, Potomac at Chain Bridge



Phase 6 Oct'14, Phosphorous, Potomac at Chain Bridge

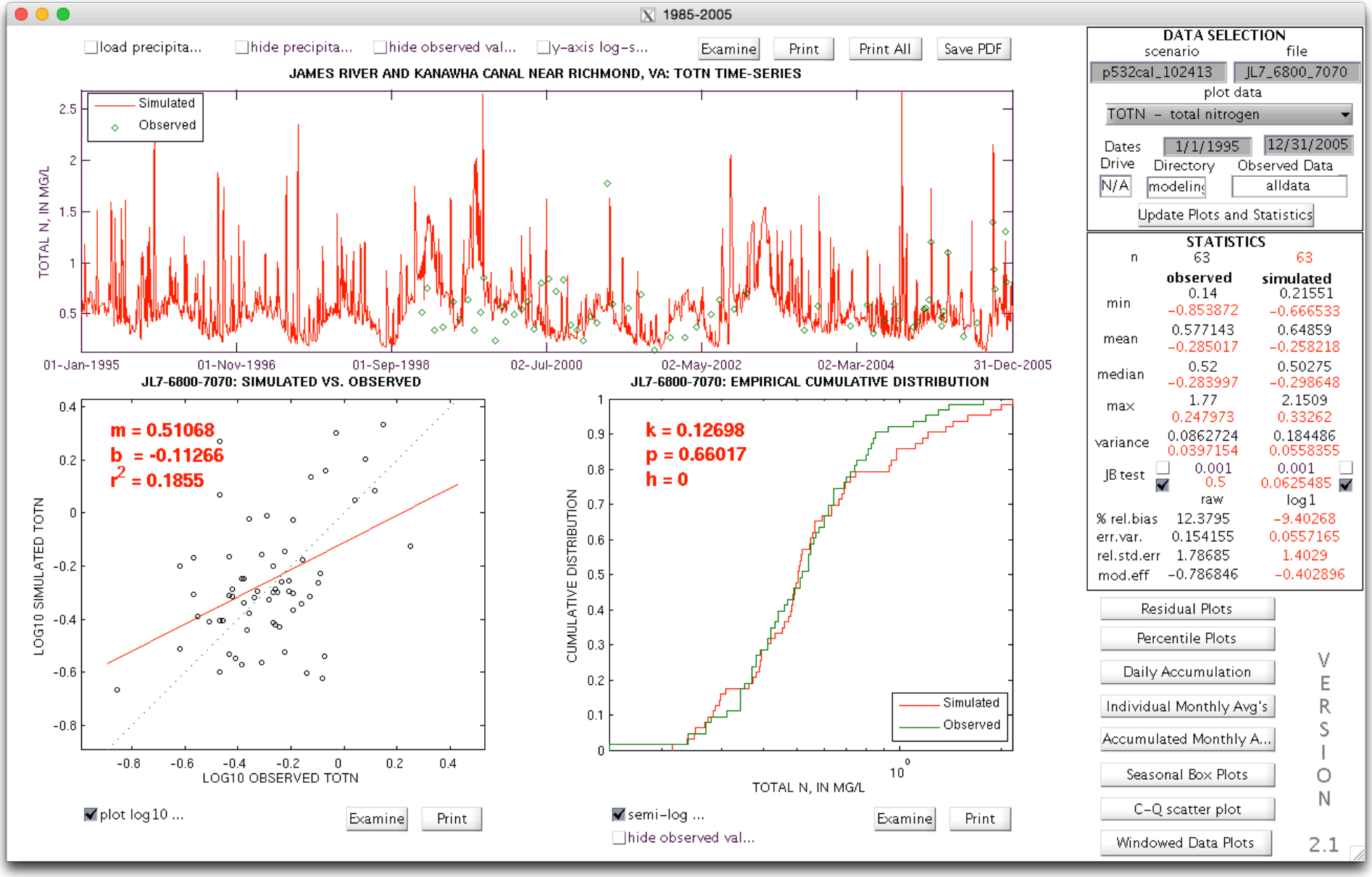


Phase 6 Apr'15, Phosphorous, Potomac at Chain Bridge

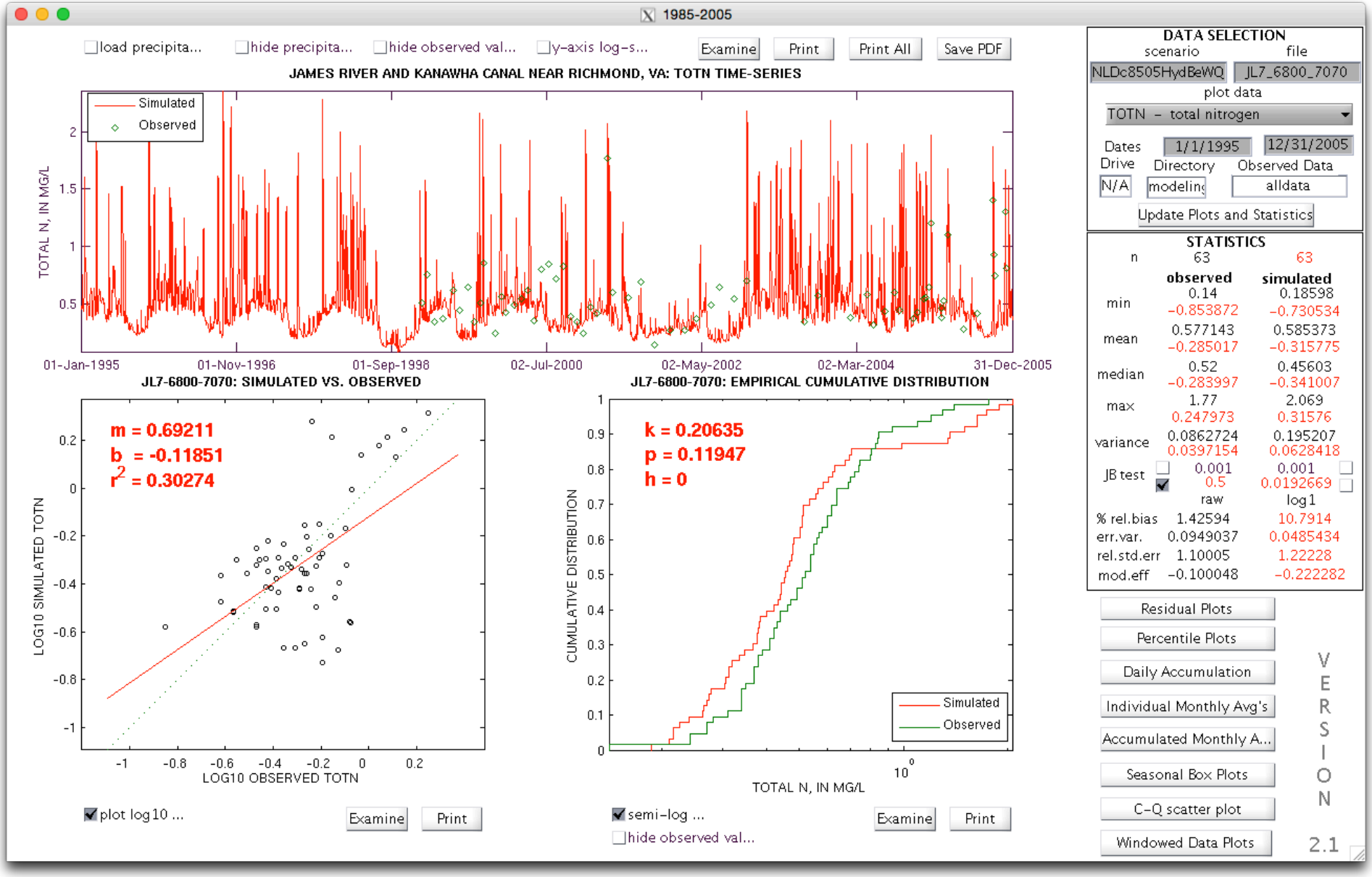


James River and Kanawha Canal near Richmond, VA

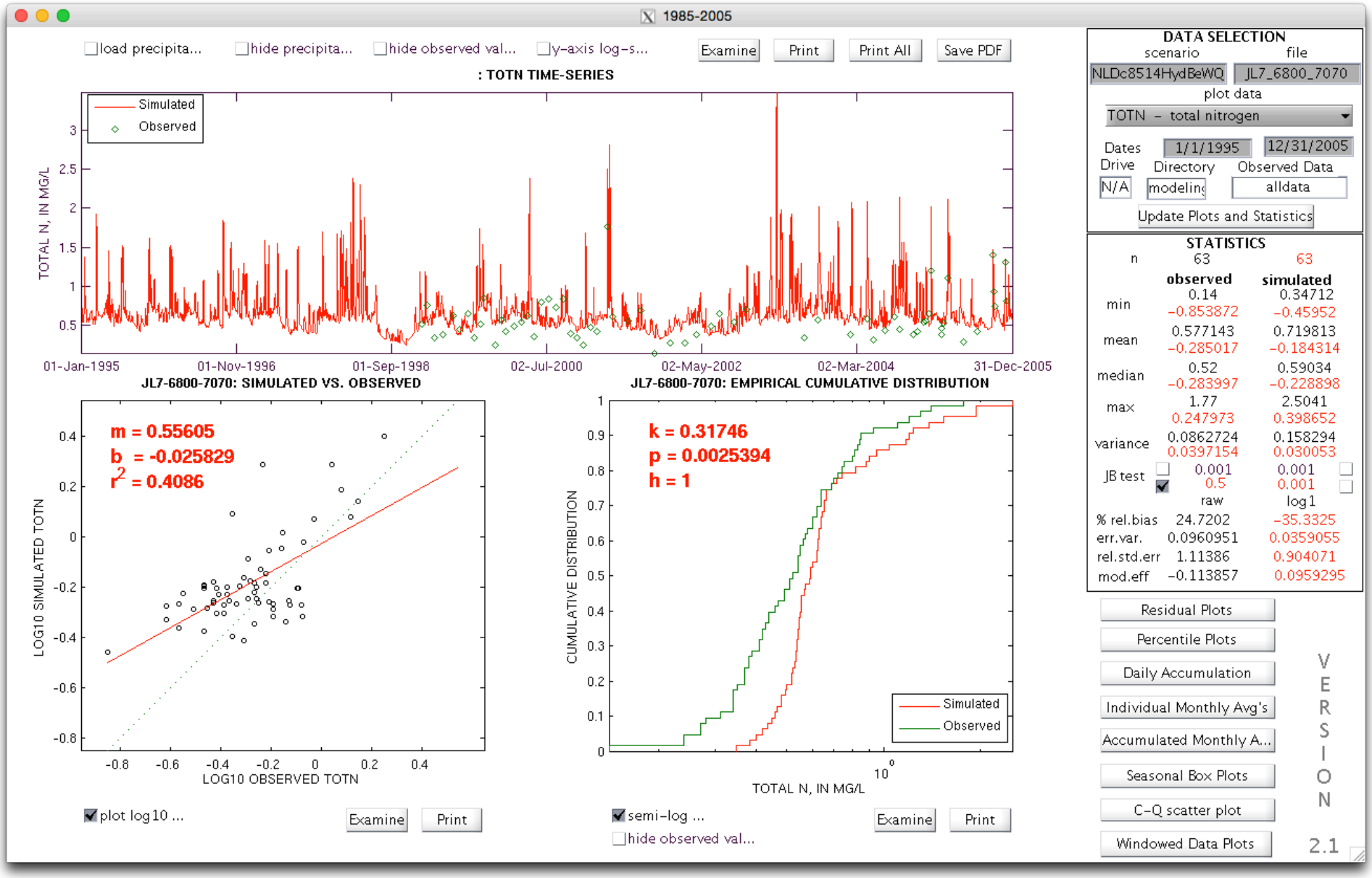
Phase 5, Nitrogen, James at Richmond



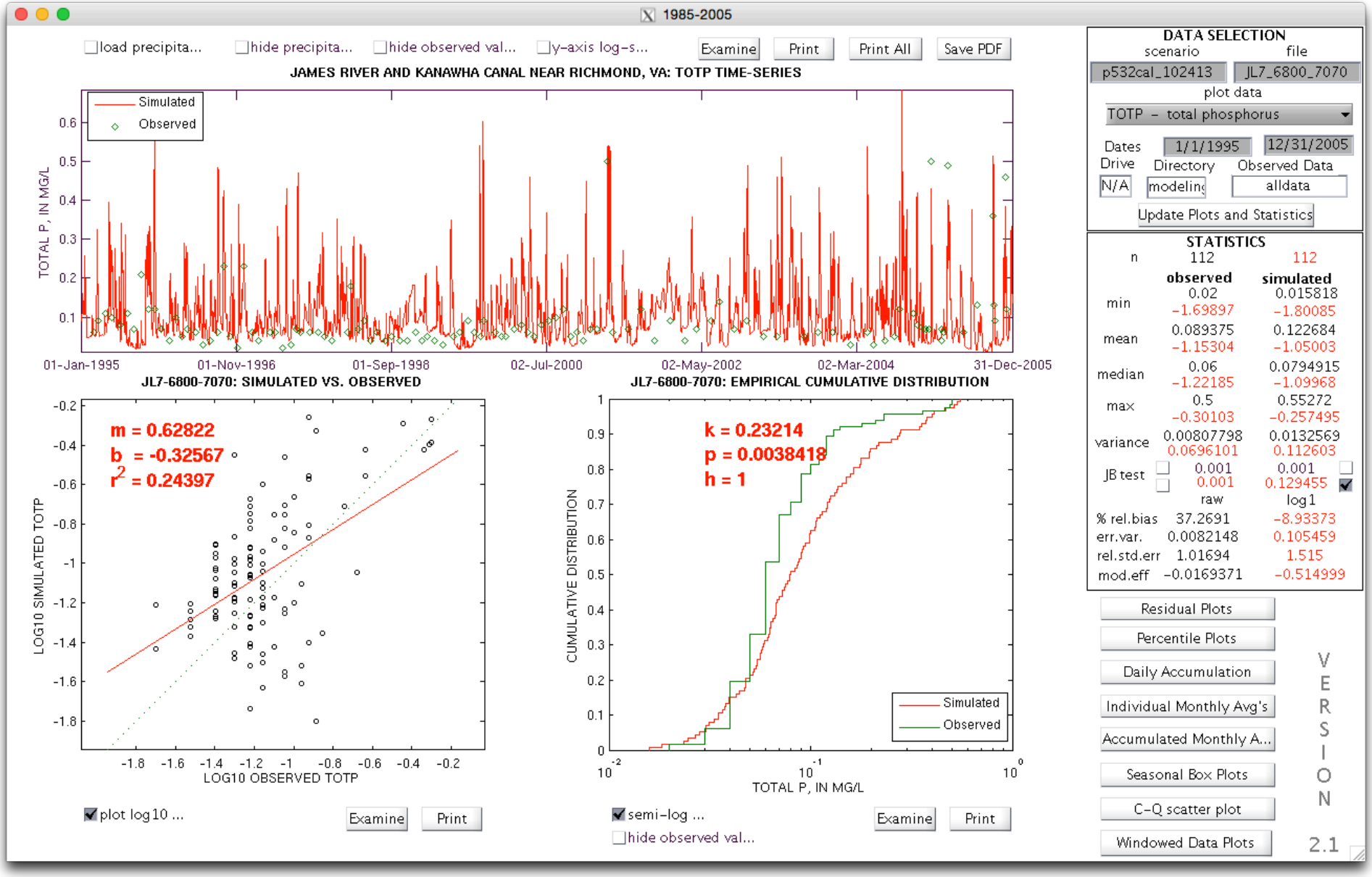
Phase 6 Oct'14, Nitrogen, James at Richmond



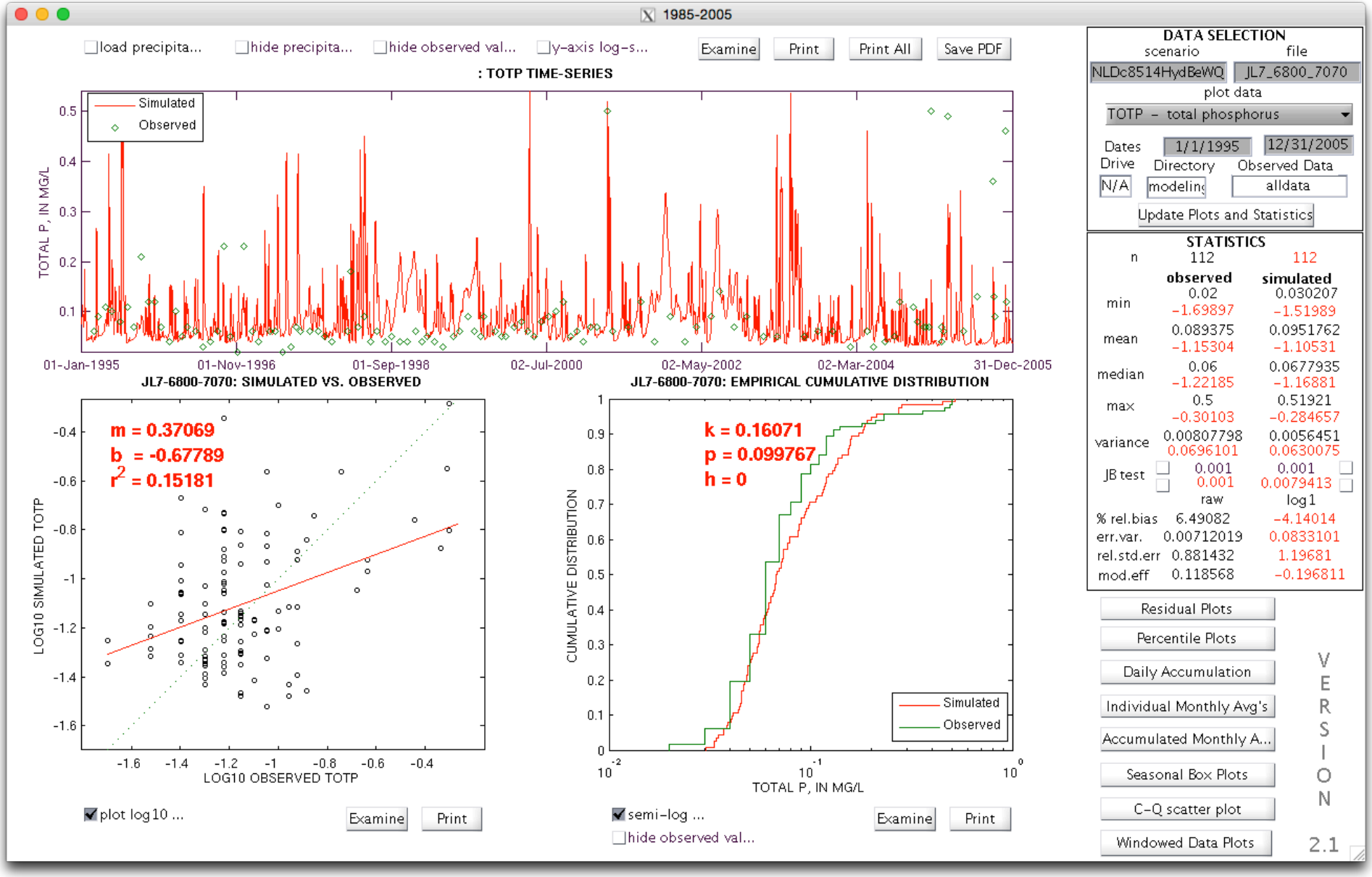
Phase 6 Apr'15, Nitrogen, James at Richmond



Phase 5, Phosphorous, James at Richmond

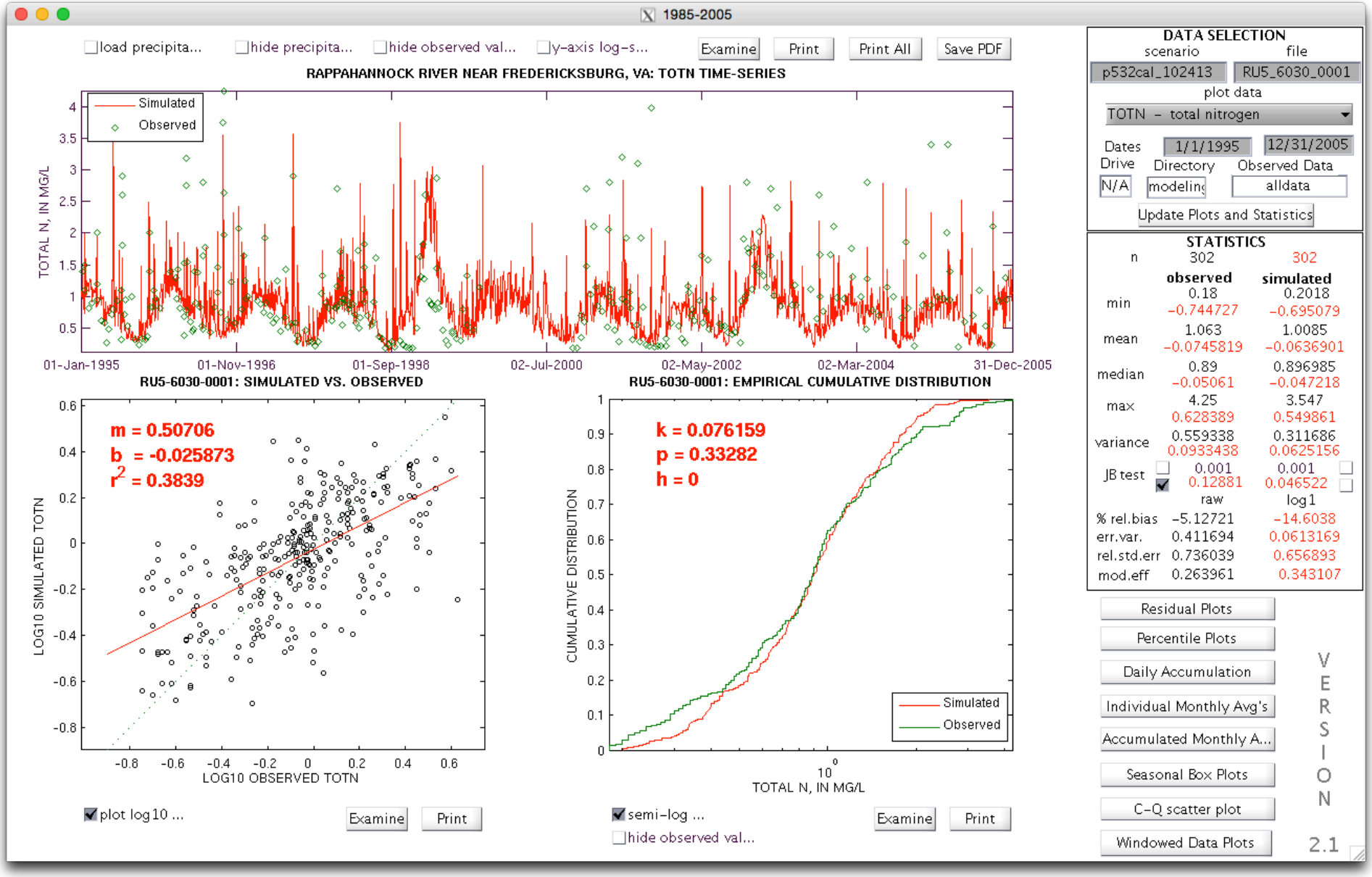


Phase 6 Apr'15, Phosphorous, James at Richmond

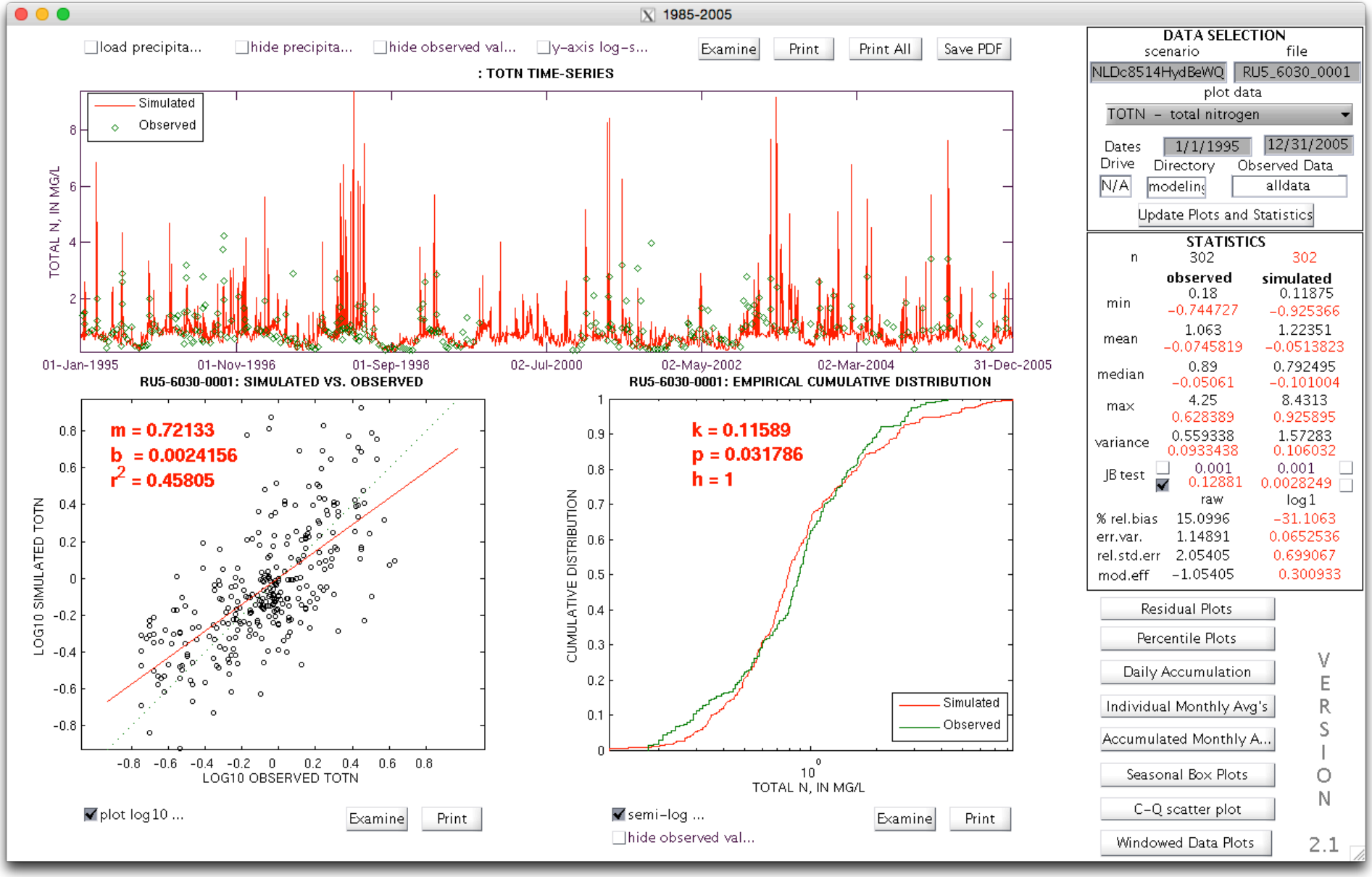


Rappahannock River at Matoaca, VA

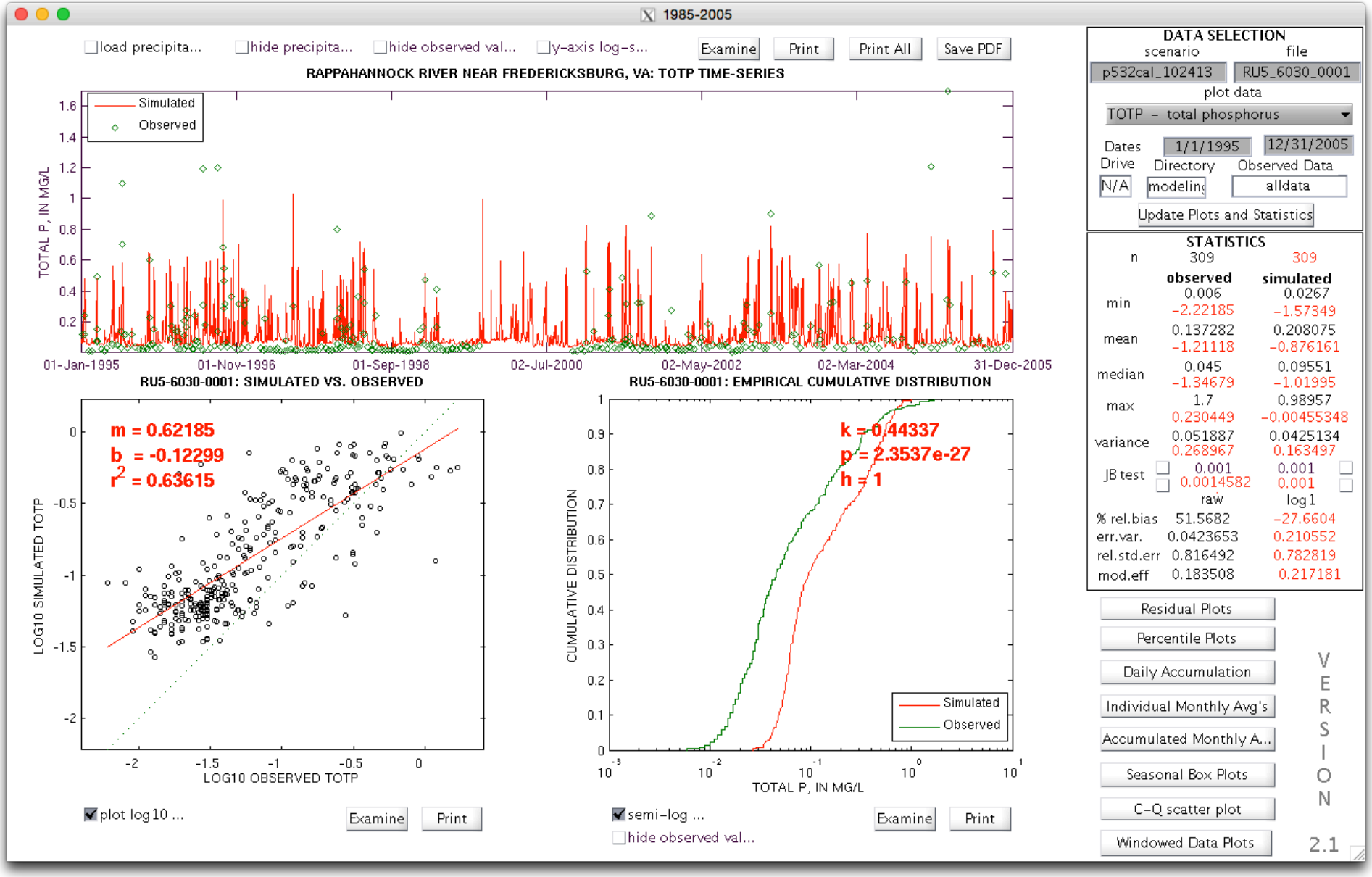
Phase 5, Nitrogen, Rappahannock at Matoaca



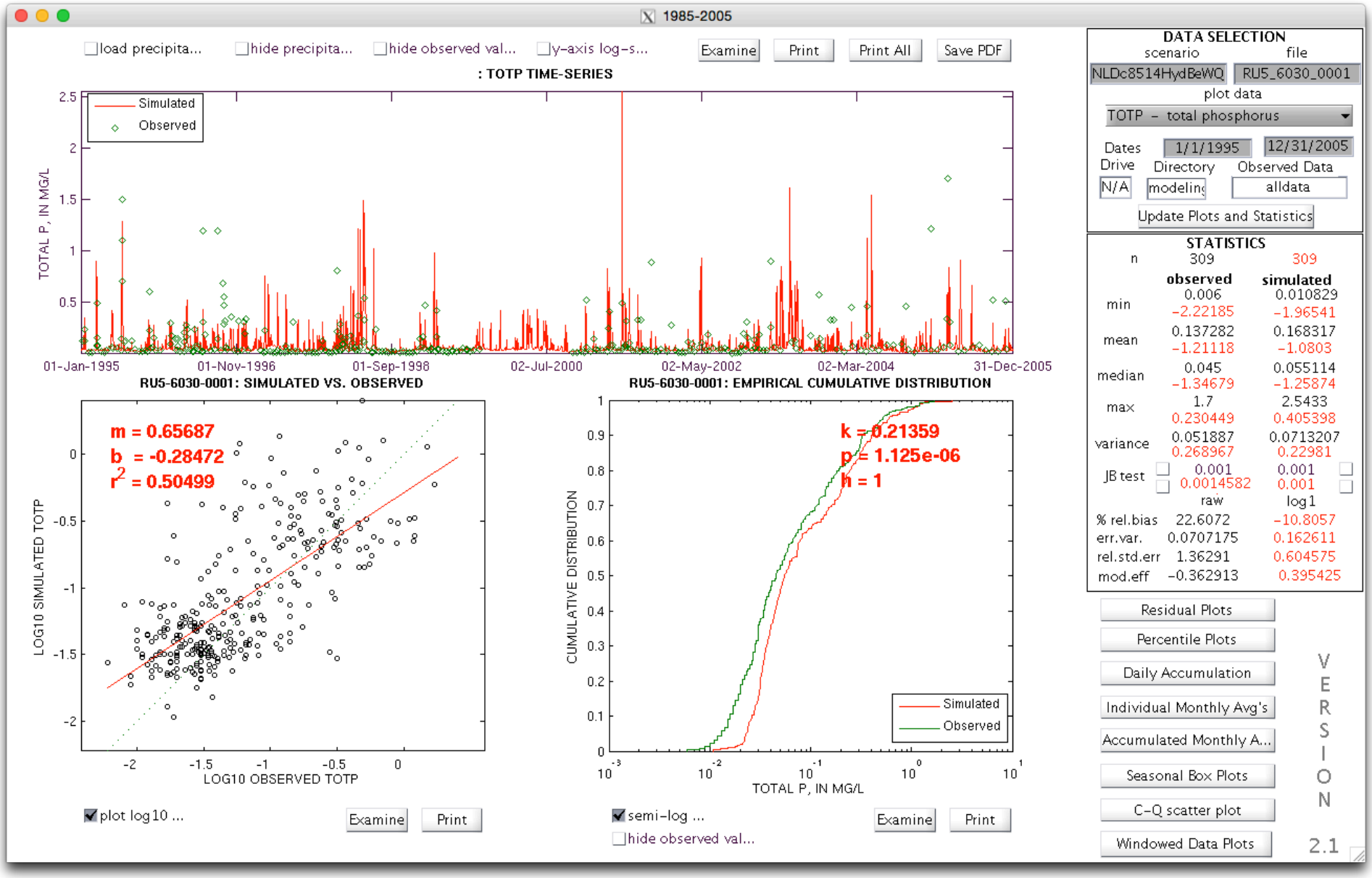
Phase 6 Apr'15, Nitrogen, Rappahannock at Matoaca

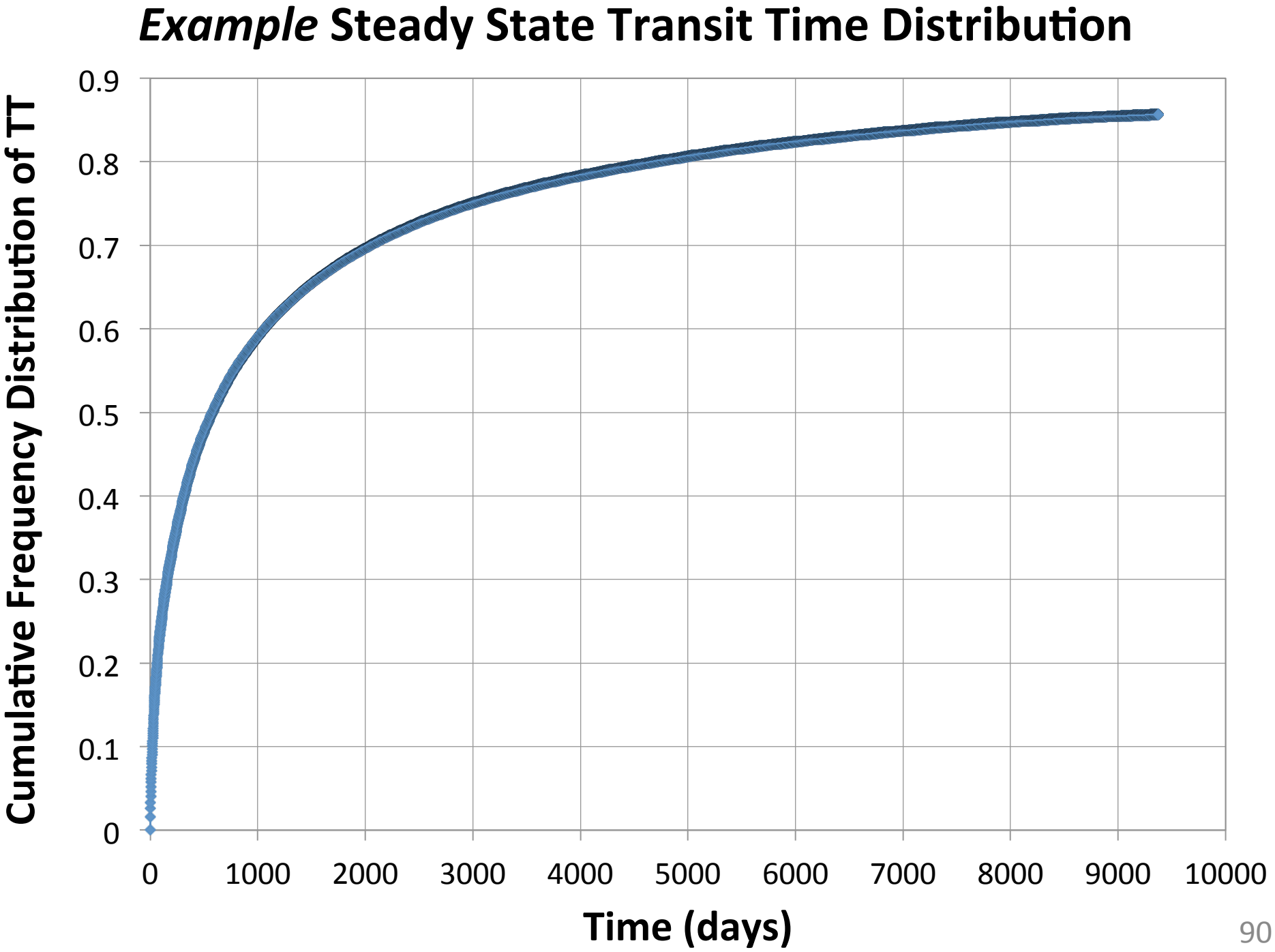


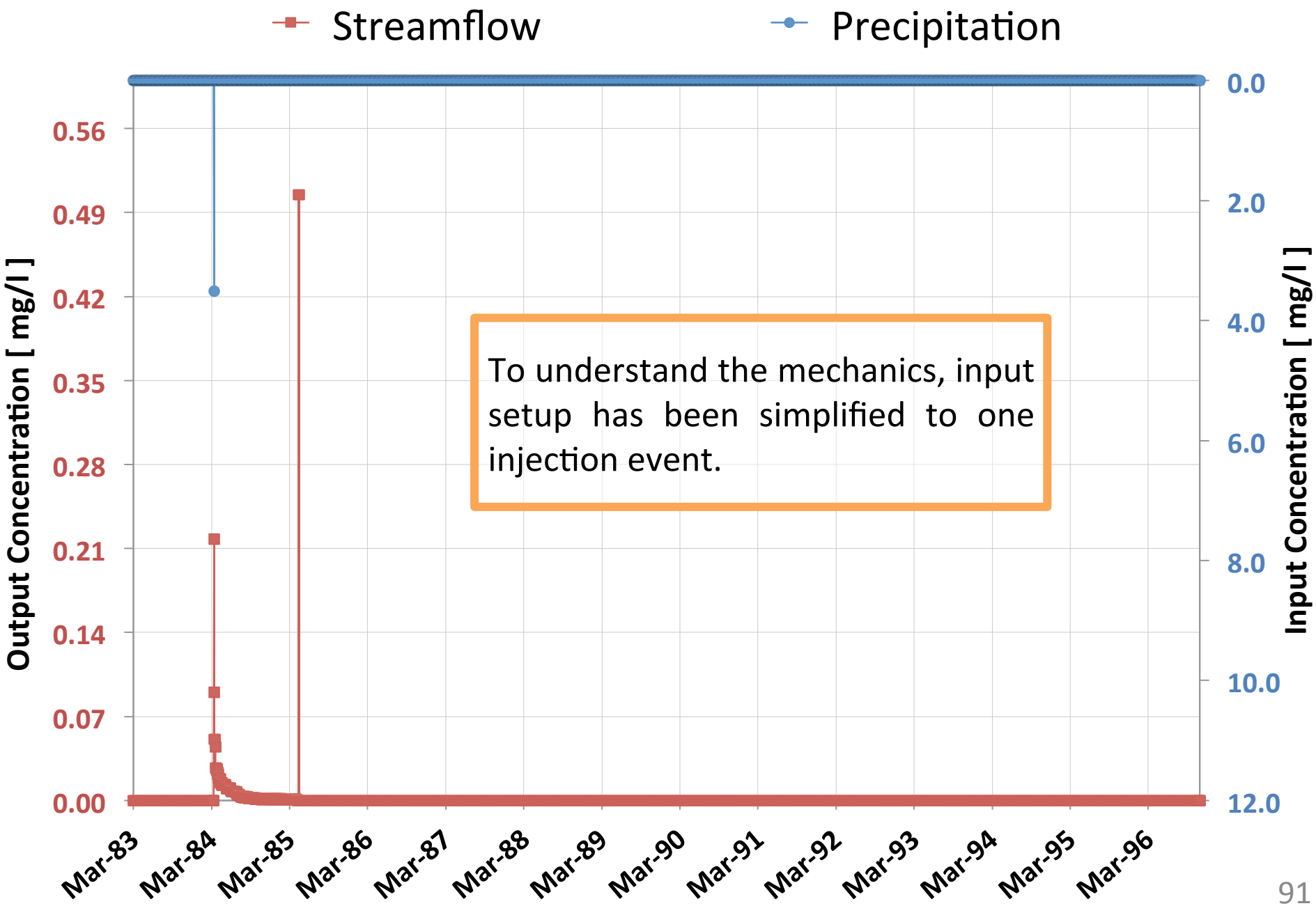
Phase 5, Phosphorous, Rappahannock at Matoaca

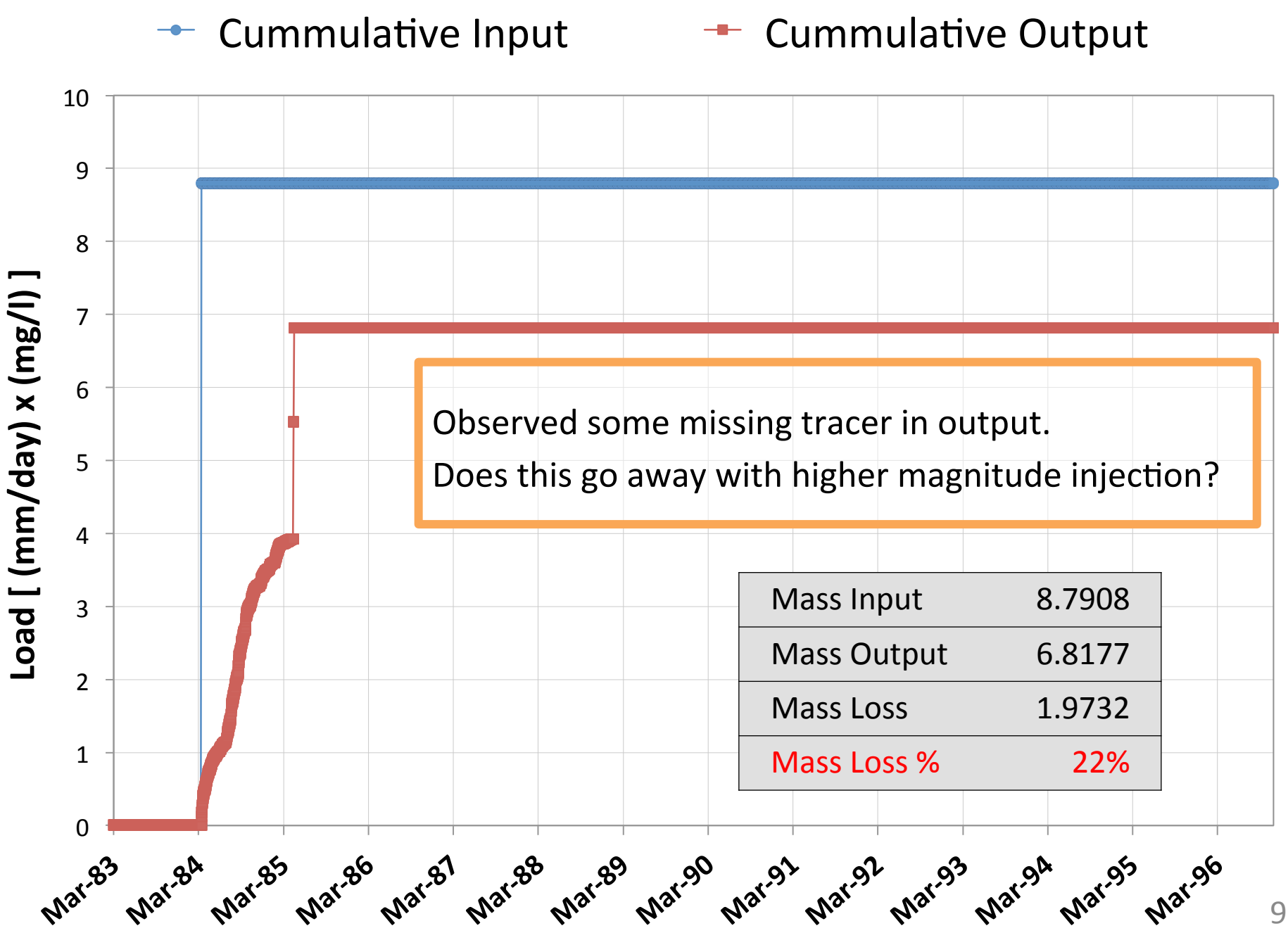


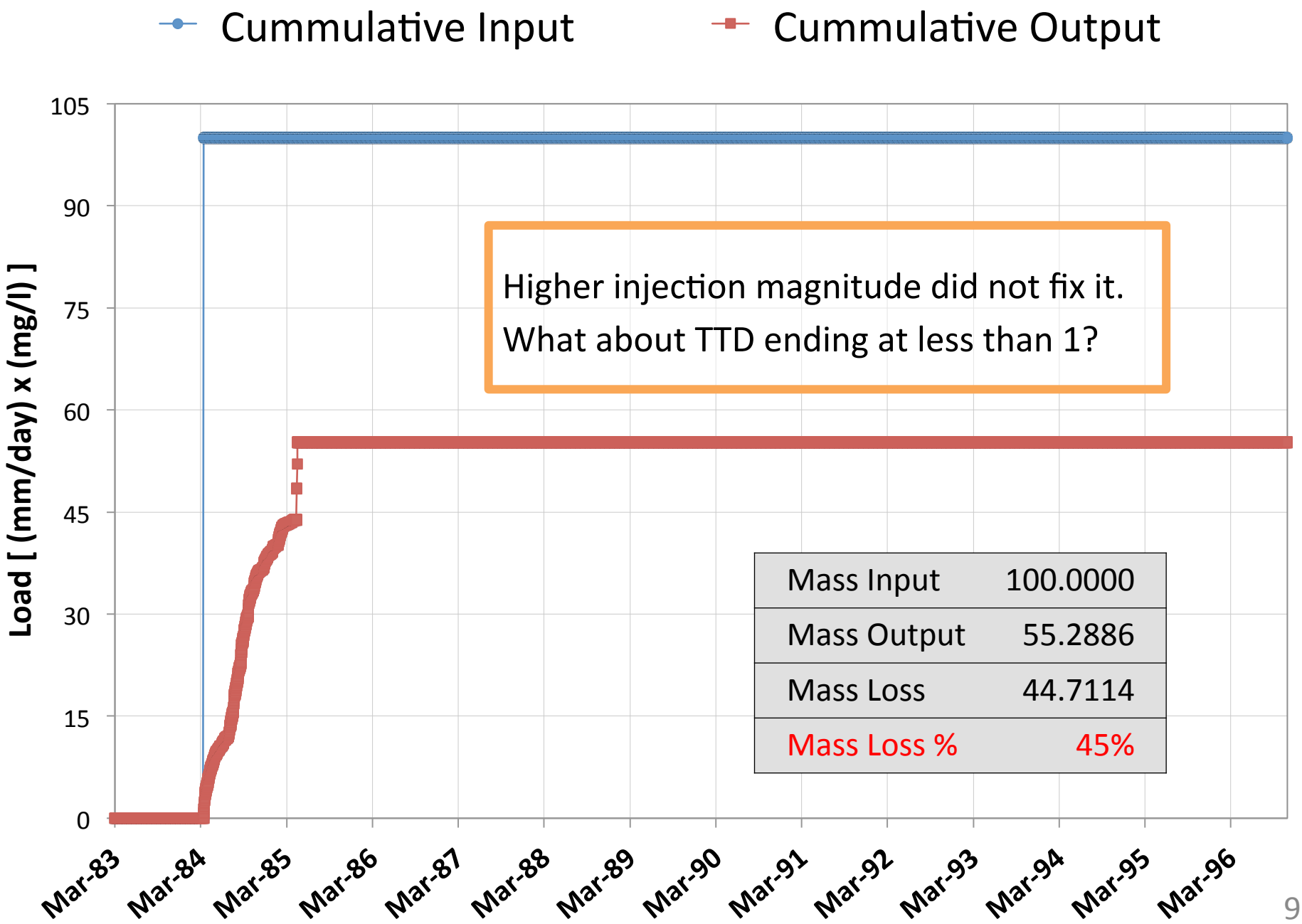
Phase 6 Apr'15, Phosphorous, Rappahannock at Matoaca

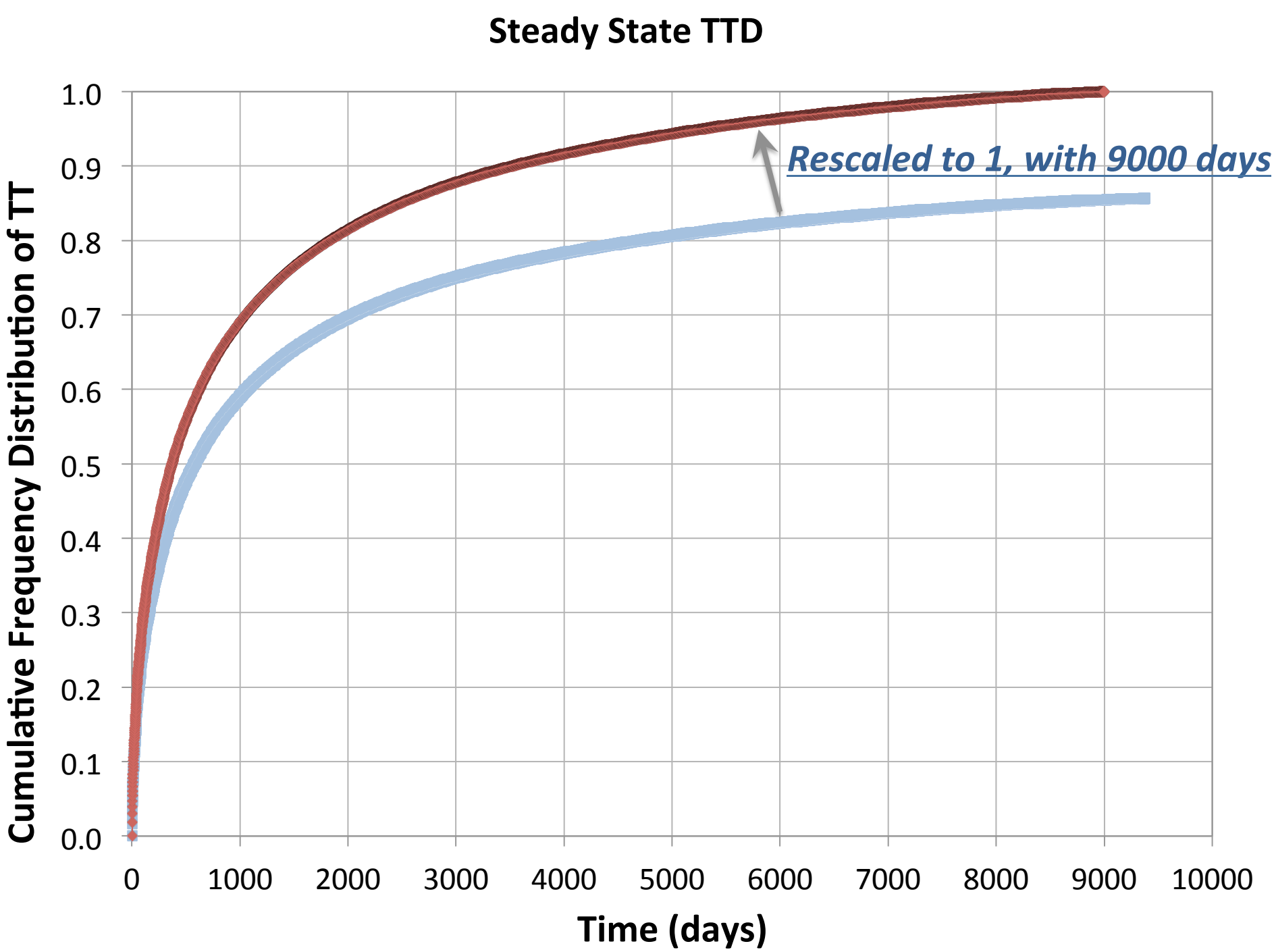



Example Steady State Transit Time Distribution
Cumulative Frequency Distribution of TT
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Time (days)

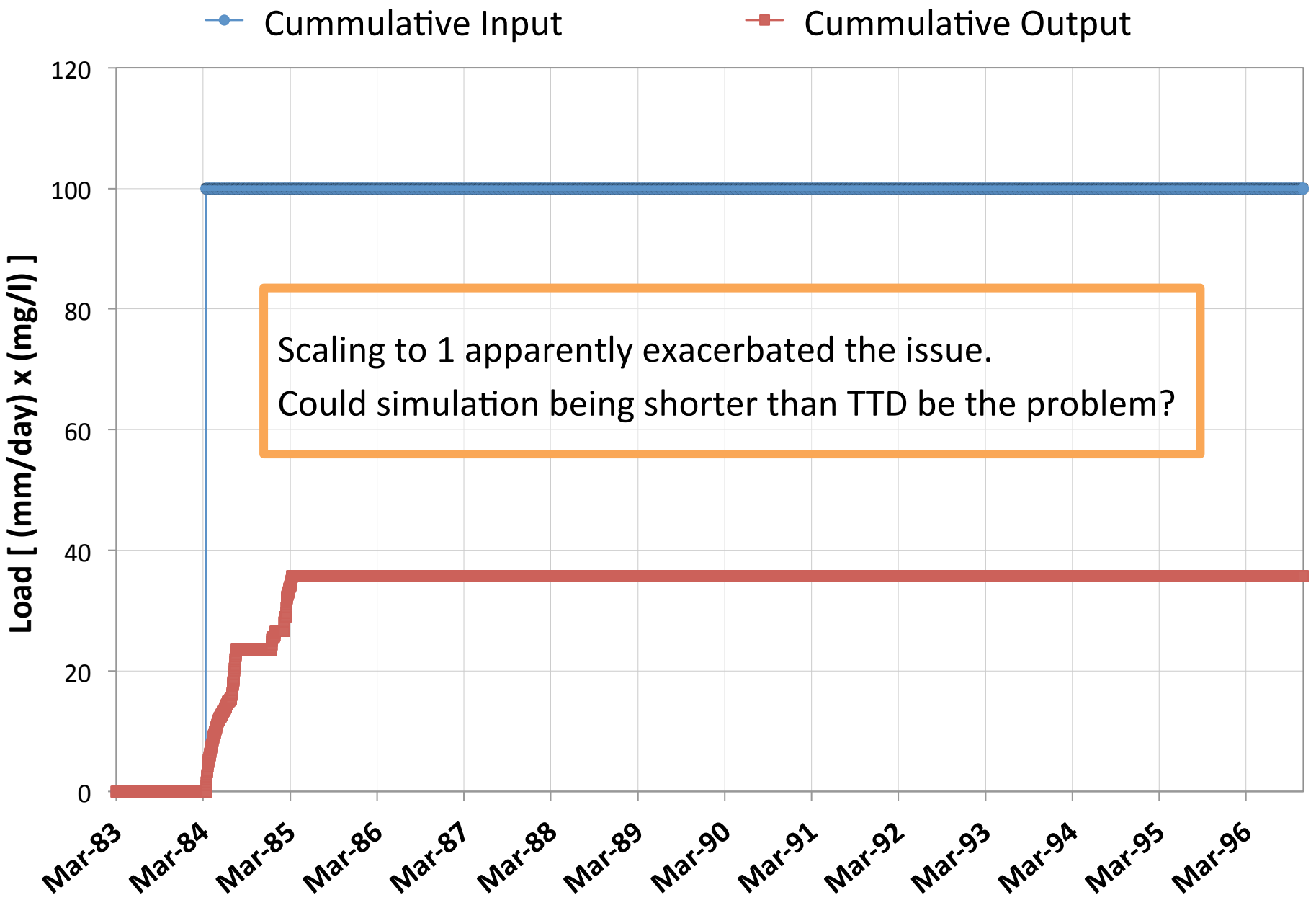

Streamflow
Precipitation
Output Concentration [mg/l]
Input Concentration [mg/l]
0.56
0.49
0.42
0.35
0.28
0.21
0.14
0.07
0.00
0.0
2.0
4.0
6.0
8.0
10.0
12.0
Mar-83
Mar-84
Mar-85
Mar-86
Mar-87
Mar-88
Mar-89
Mar-90
Mar-91
Mar-92
Mar-93
Mar-94
Mar-95
Mar-96
To understand the mechanics, input setup has been simplified to one injection event.

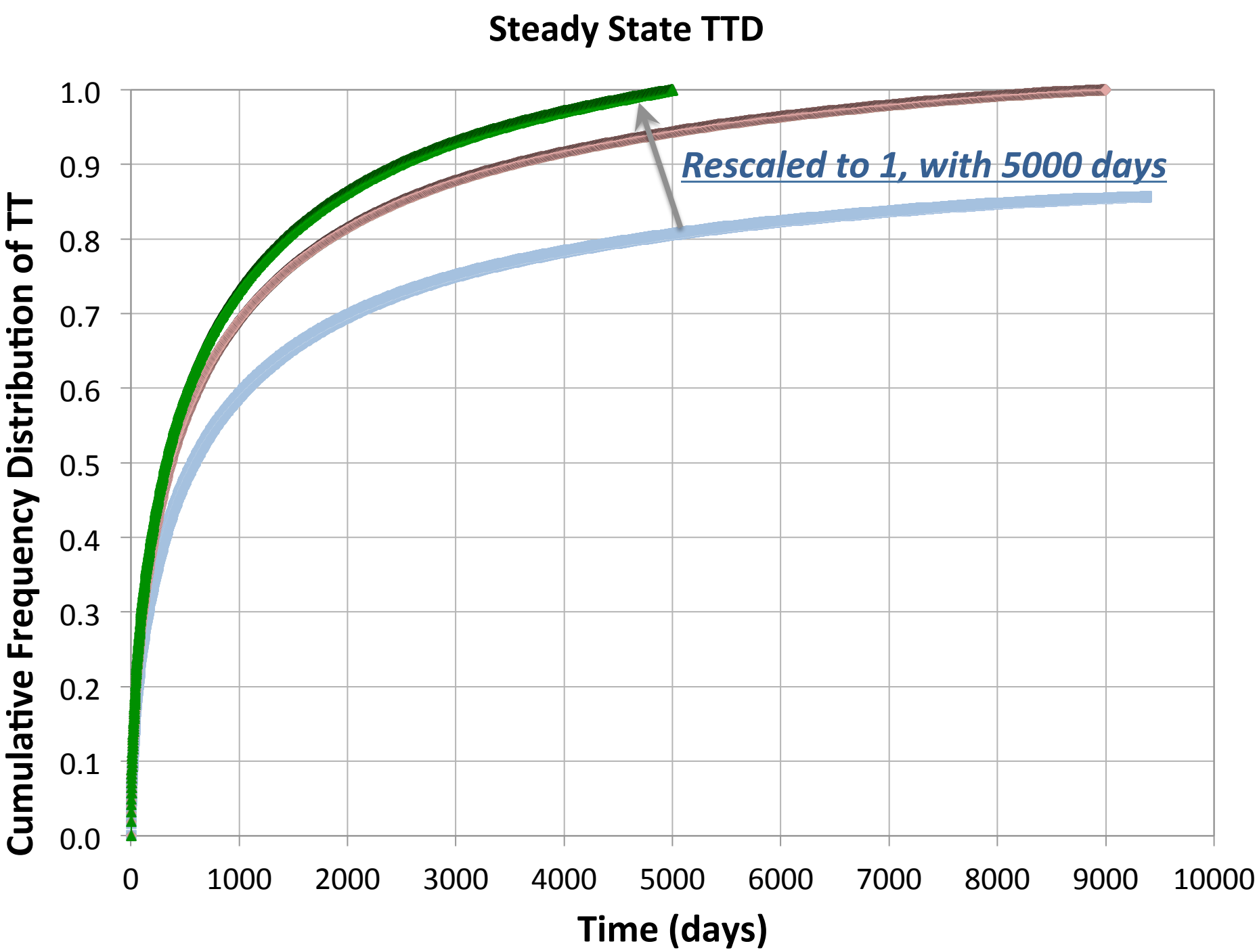

Cummulative Input
Cummulative Output
Load [(mm/day) x (mg/l)]
10
9
8
7
6
5
4
3
2
1
0
Mar-83
Mar-84
Mar-85
Mar-86
Mar-87
Mar-88
Mar-89
Mar-90
Mar-91
Mar-92
Mar-93
Mar-94
Mar-95
Mar-96
Observed some missing tracer in output.
Does this go away with higher magnitude injection?
Mass Input 8.7908
Mass Output 6.8177
Mass Loss 1.9732
Mass Loss % 22%

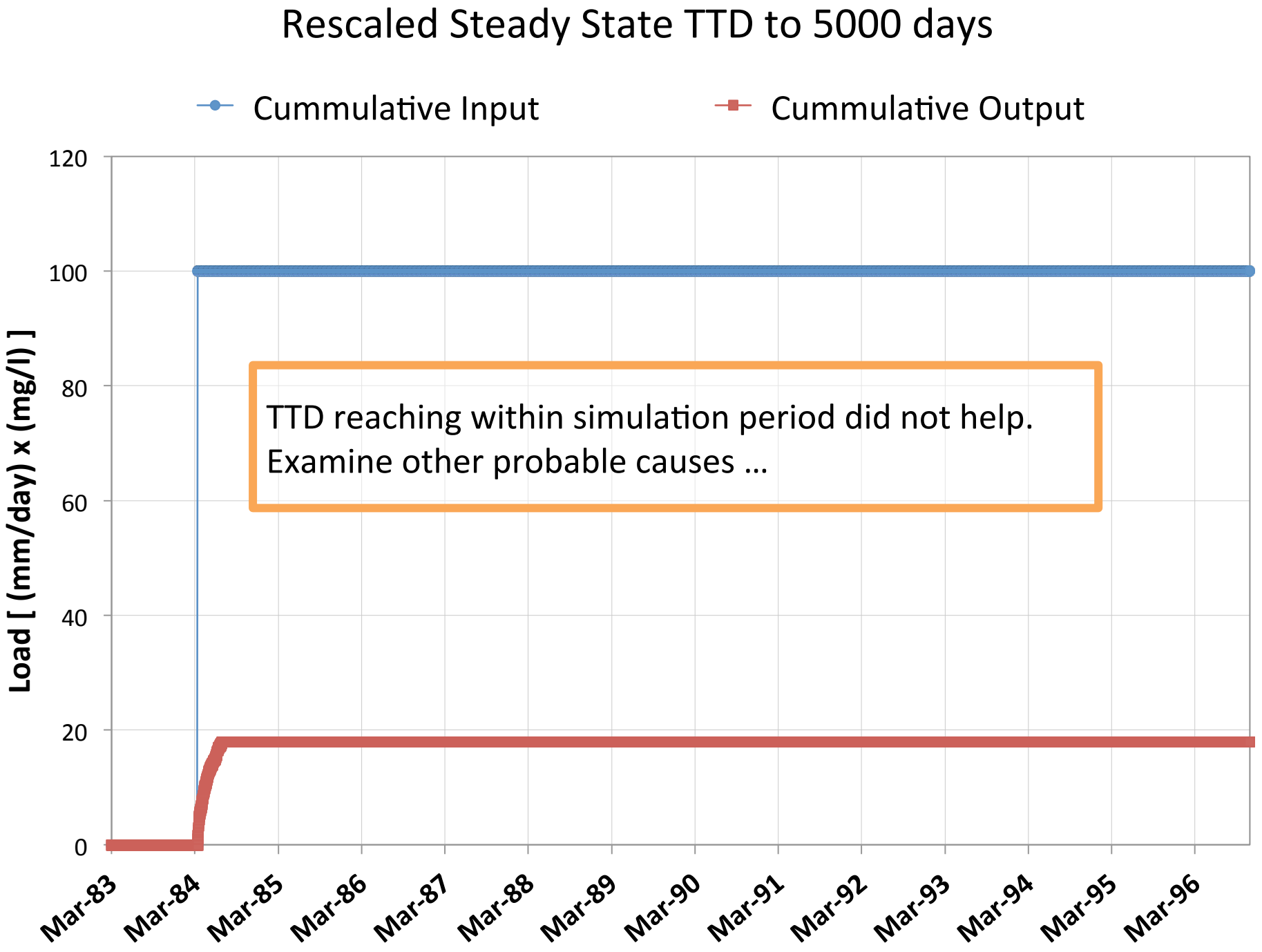

Cummulative Input
Cummulative Output
Load [(mm/day) x (mg/l)]
105
90
75
60
45
30
15
0
Mar-83
Mar-84
Mar-85
Mar-86
Mar-87
Mar-88
Mar-89
Mar-90
Mar-91
Mar-92
Mar-93
Mar-94
Mar-95
Mar-96
Higher injection magnitude did not fix it.
What about TTD ending at less than 1?
Mass Input 100.0000
Mass Output 55.2886
Mass Loss 44.7114
Mass Loss % 45%


Steady State TTD
Cumulative Frequency Distribution of TT
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Time (days)
Rescaled to 1, with 9000 days

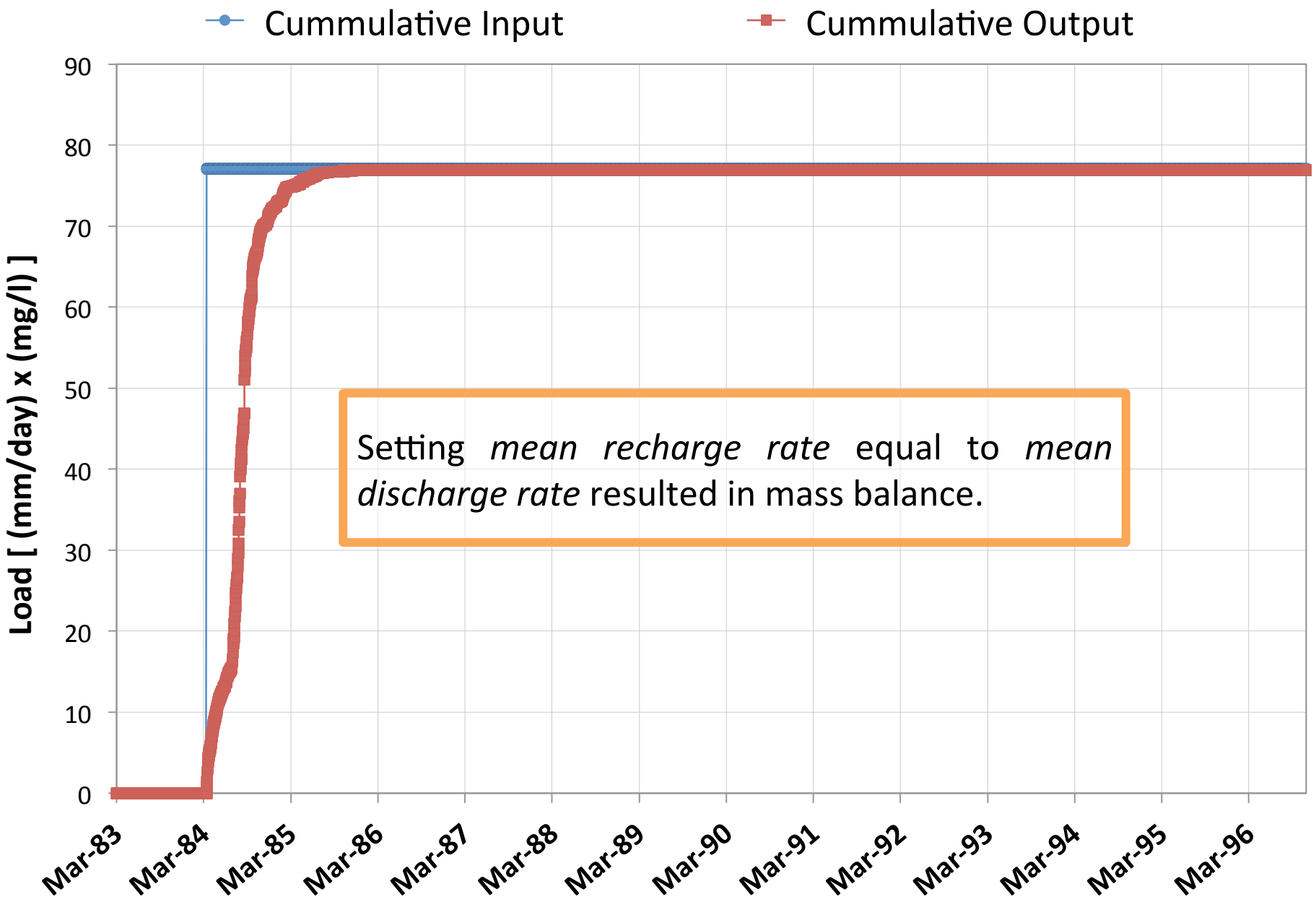
Rescaled Steady State TTD to 9000 days




Steady State TTD
Cumulative Frequency Distribution of TT
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Time (days)
Rescaled to 1, with 5000 days


Rescaled Steady State TTD to 5000 days
Cummulative Input
Cummulative Output
Load [(mm/day) x (mg/l)]
120
100
80
60
40
20
0
TTD reaching within simulation period did not help.
Examine other probable causes …
Mar-83
Mar-84
Mar-85
Mar-86
Mar-87
Mar-88
Mar-89
Mar-90
Mar-91
Mar-92
Mar-93
Mar-94
Mar-95
Mar-96

Rescaled Steady State TTD to 5000 days, and ***P_Eff = Q***



rSAS for *groundwater nitrate* transport

A42105 – forest : { P, C_i, Q } → { C_o }

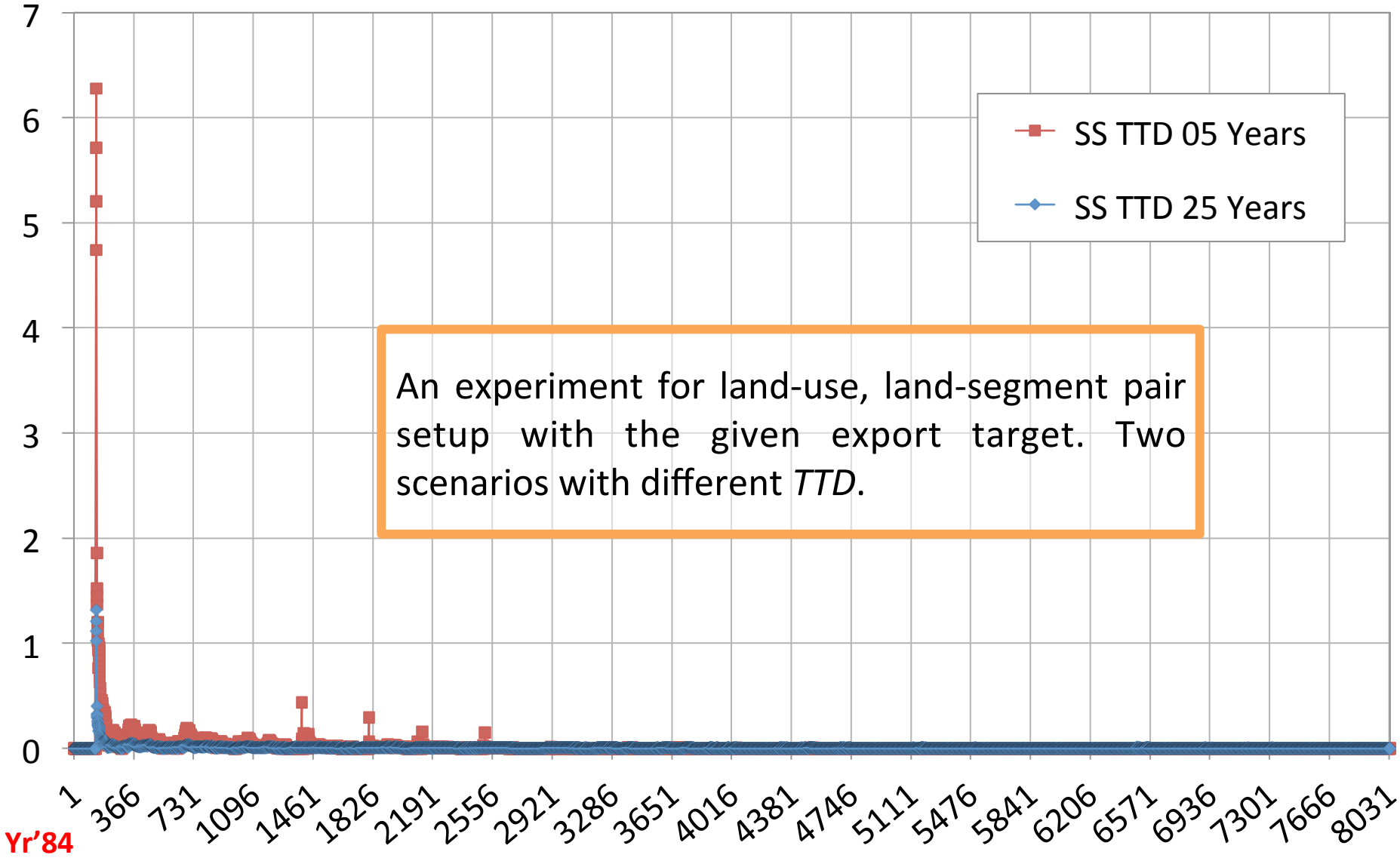
- P = daily precipitation
- C_i = total monthly application / total monthly P
- Q = simulated base-flow (AGWO)

- *P_Eff* = scale P to match Q
- *rSAS param.* = mean of Q

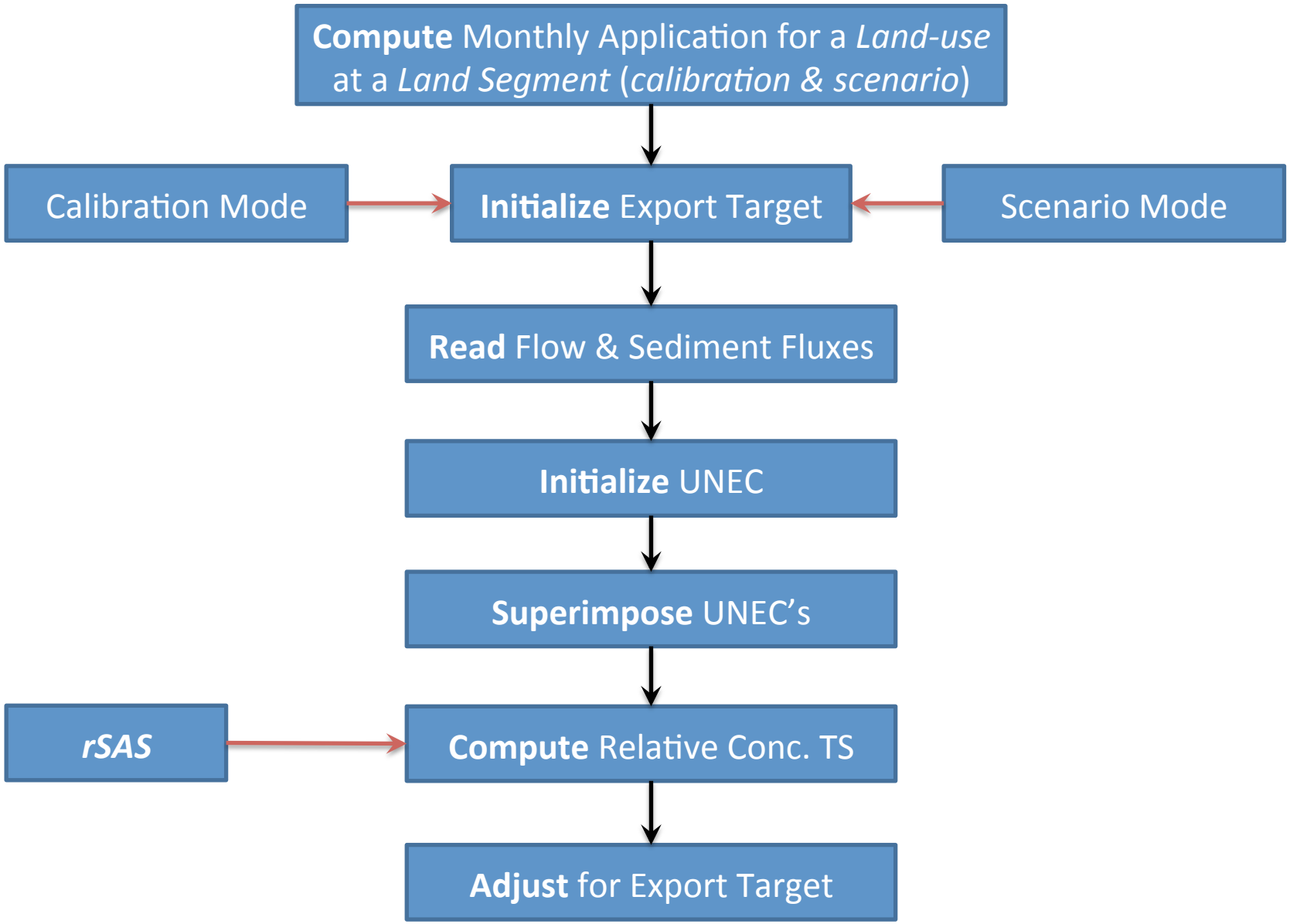
[*** rSAS simulation ***]

- C_o = scale C_o to match export target

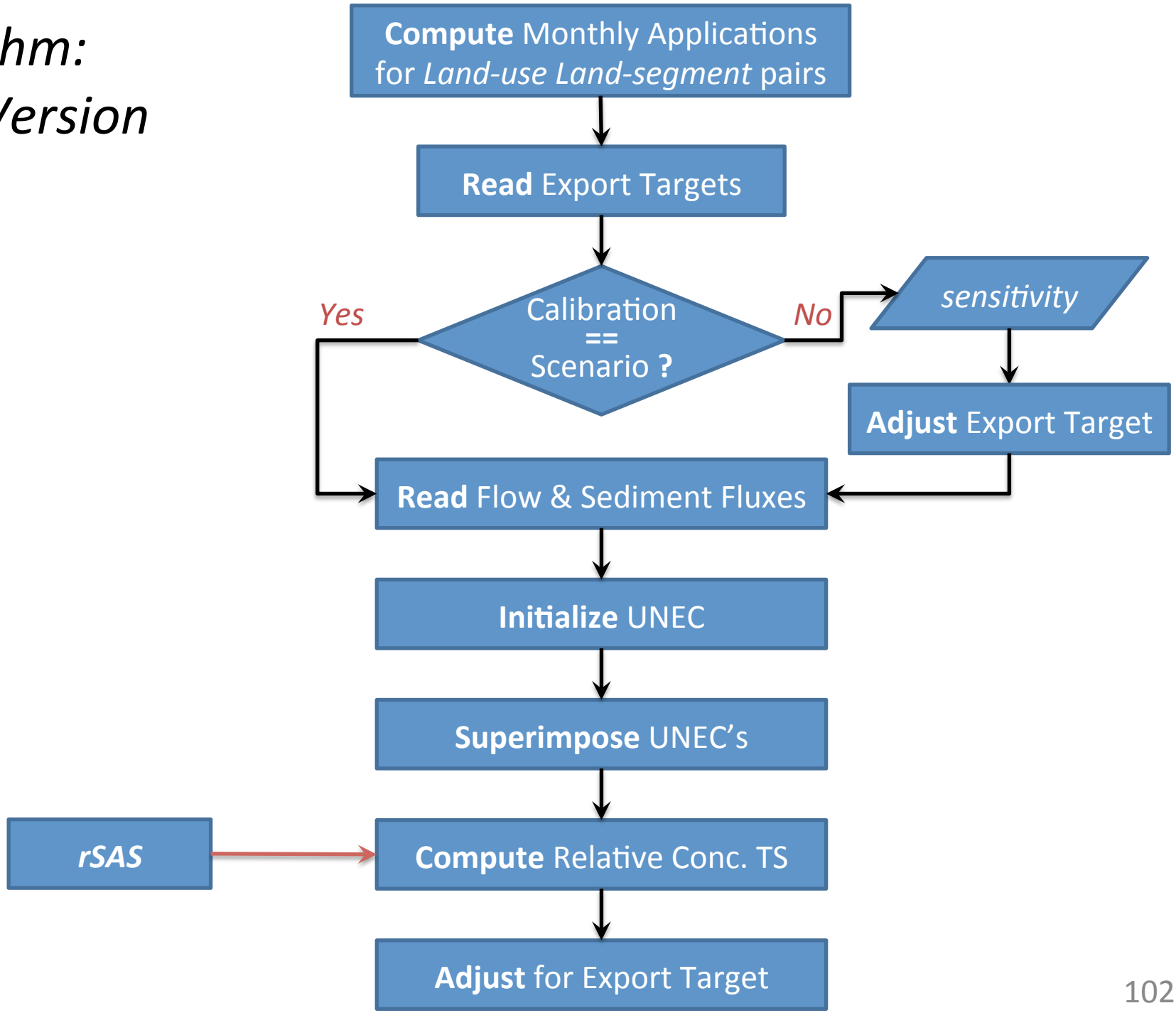
What if: one input, *and* avg. annual export target



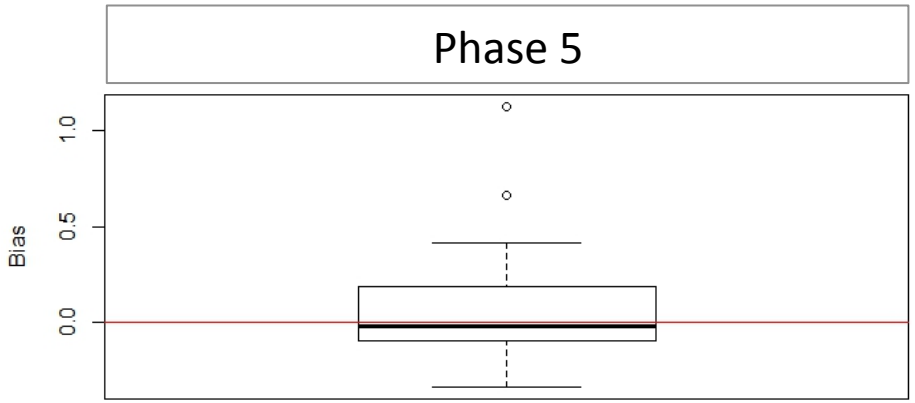
Algorithm: Short Version

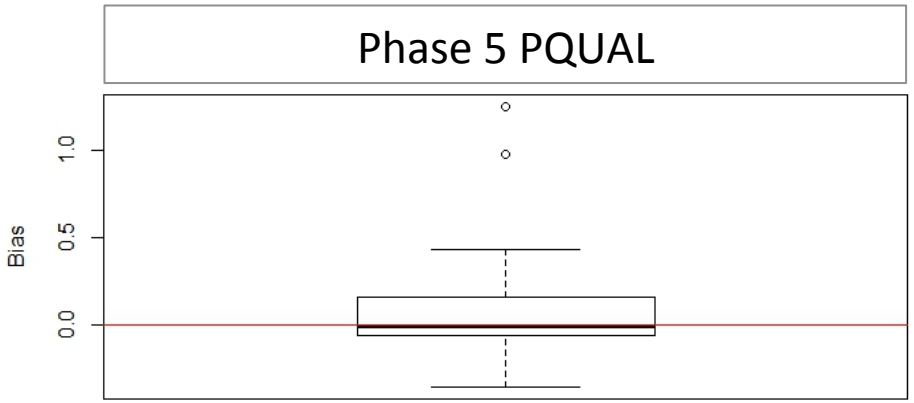


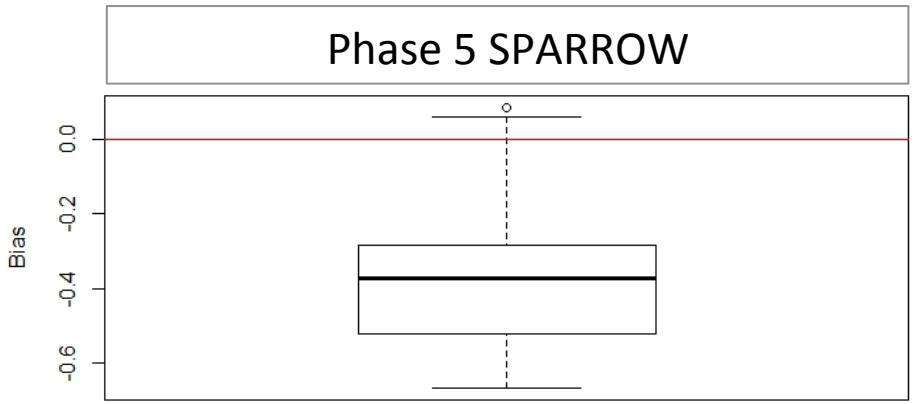
Algorithm: Short Version

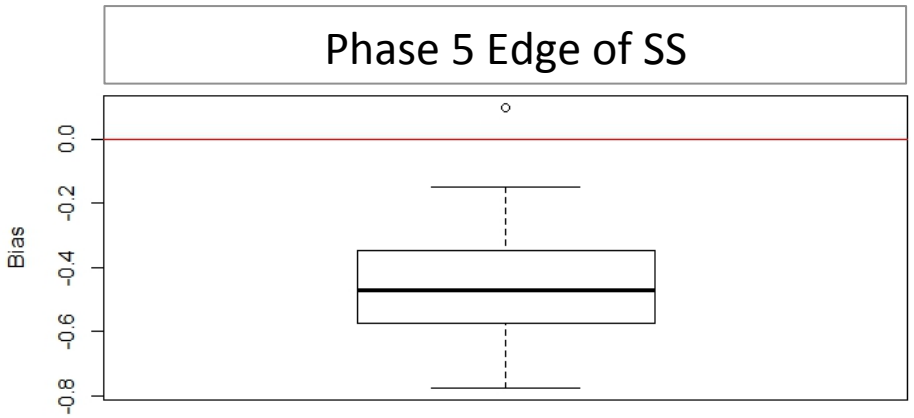


Nitrogen Loads: Simulated vs. USGS-ESTIMATOR

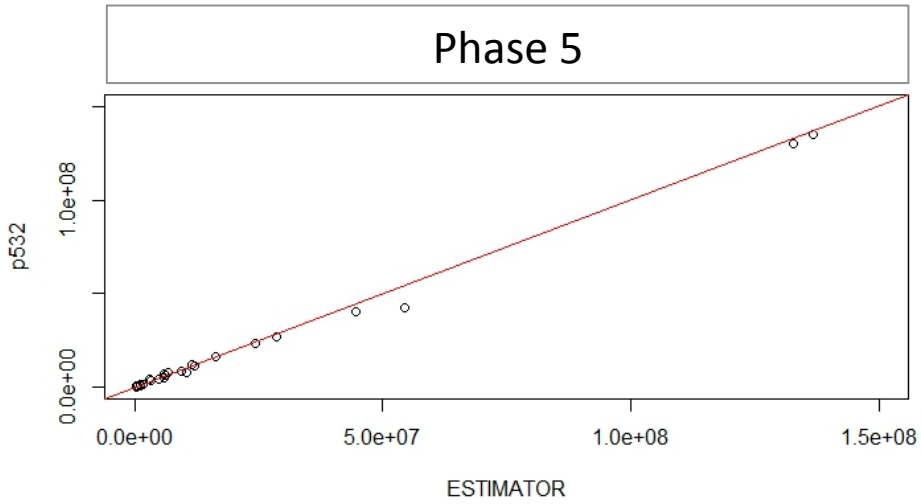


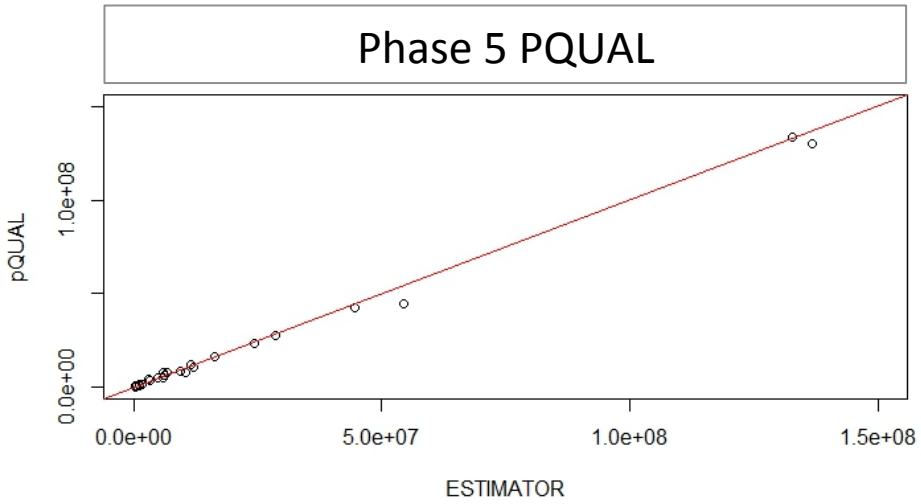


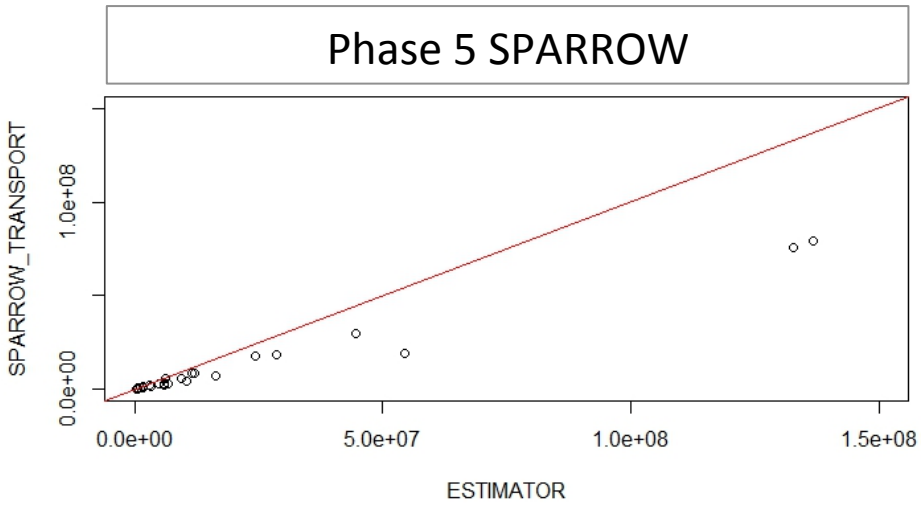


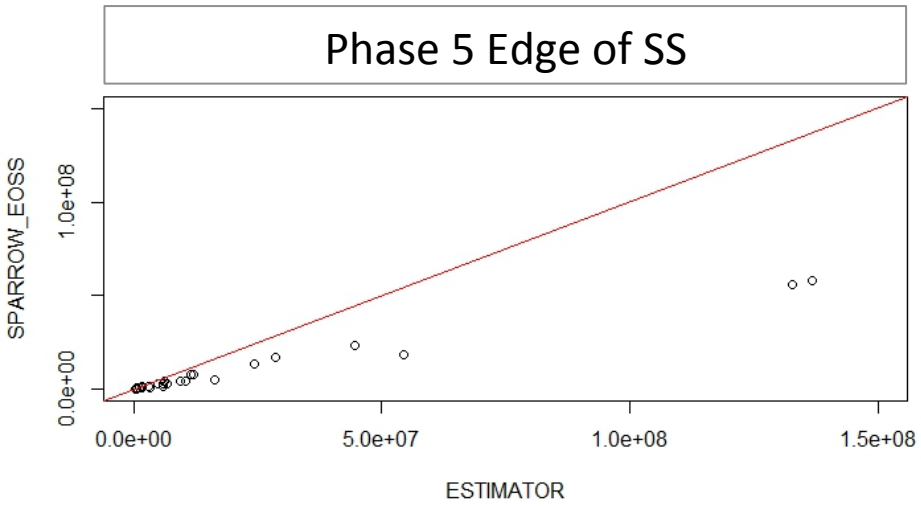


Nitrogen Loads: Simulated vs. USGS-ESTIMATOR

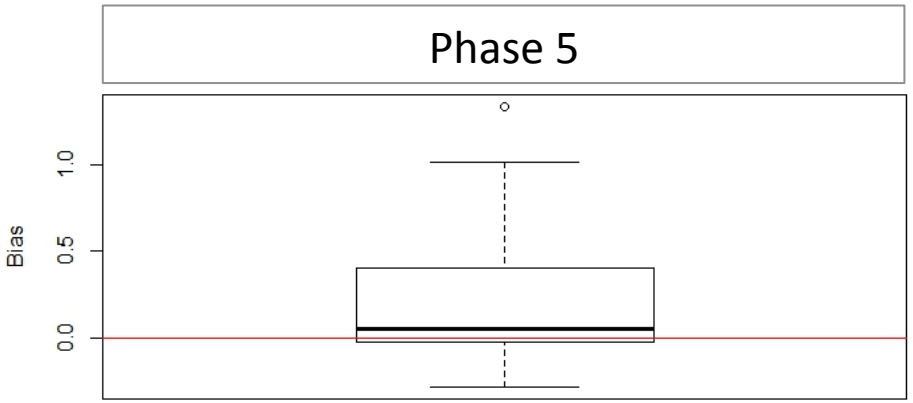


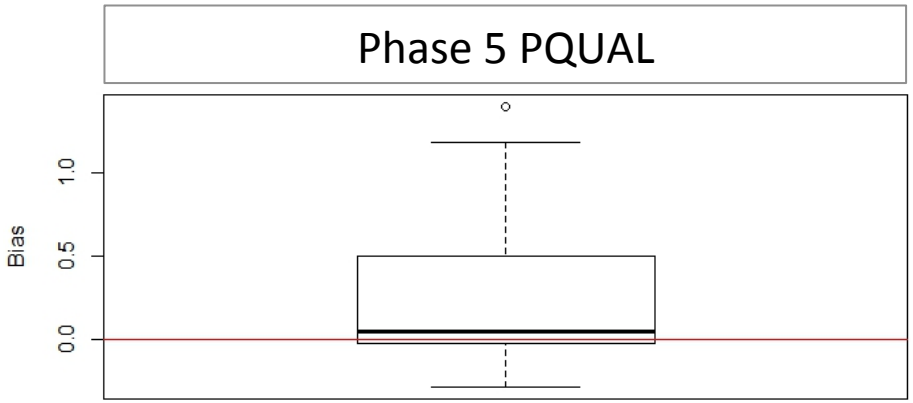


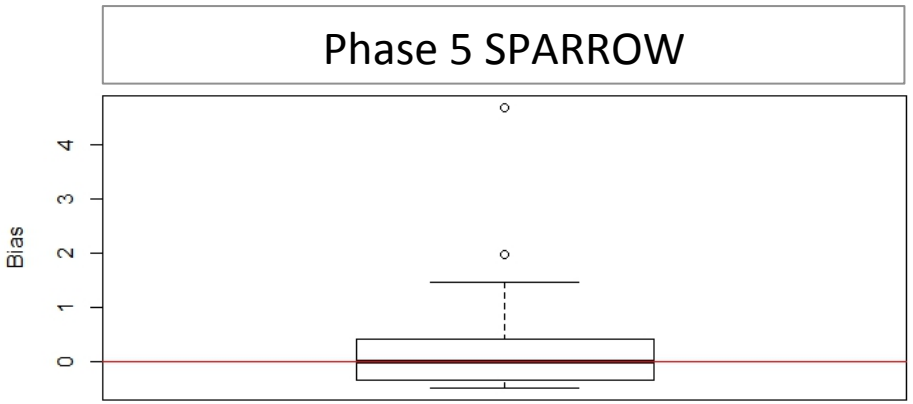


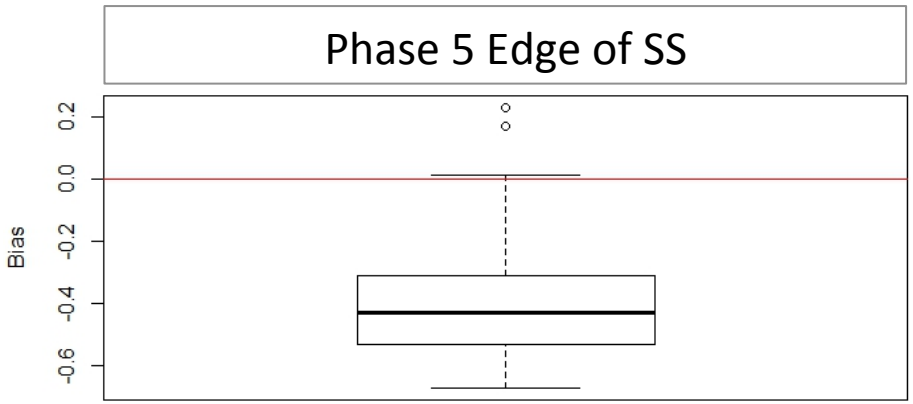


Phosphorous Loads: Simulated vs. USGS-ESTIMATOR









Phosphorous Loads: Simulated vs. USGS-ESTIMATOR