07/09/2024

Phase 7 WSM Development – Water Quality Calibration (Step 1)

Modeling Workgroup Quarterly Meeting – July 2024

Gopal Bhatt[1], Isabella Bertani[2], Lewis Linker[3], Robert Burgholzer[4]

[1] Penn State, [2] UMCES, [3] US EPA, [4] VA DEQ – Chesapeake Bay Program Office

Presentation Outline

Phase 7 Dynamic Watershed Model (DWM)

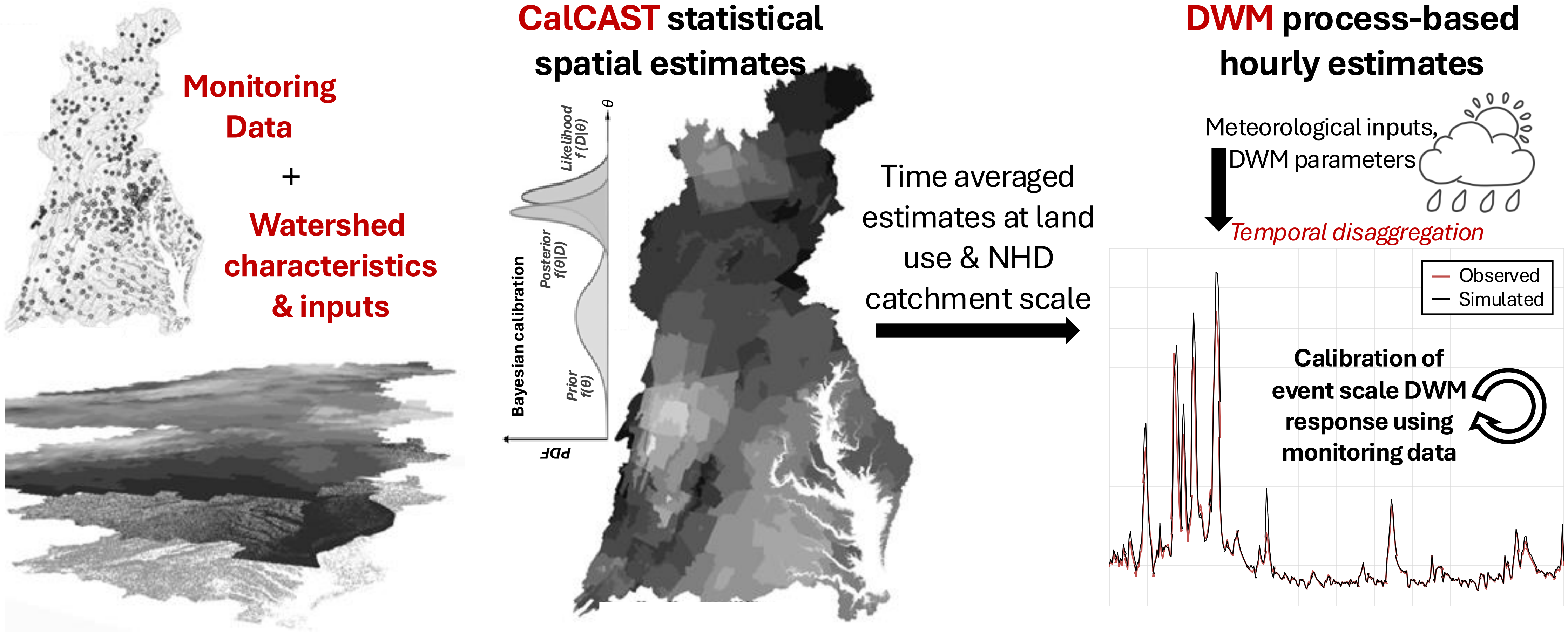
1. **Dynamic Watershed Model Overview**
2. **Review of prior model development progress**
3. **Water quality calibration**
    - Step 1: mechanics of water quality calibration
    - Step 2: revisions to the calibration methods
    - Small stream Q-C relationship
4. **Summary and next steps**

Purpose

NHD Scale Dynamic Watershed Model (DWM)

- Inputs for the estuarine models (MBM/MTMs)
- Watershed model calibration and scenario applications
- Support research and collaboration activities

Framework: Statistical Model (CalCAST) → Dynamic Watershed Model (DWM)



- Data-driven CalCAST informs DWM parameters and responses.
- NHD-scale DWM prototype is now using CalCAST *average annual* (a) total flow, (b) stormflow, (c) sediment erosion and delivery factors, and (d) total nitrogen and total phosphorus loads and delivery factors.

Dynamic Watershed Model (DWM) Development

- **Year 2022: NHD-scale model structure and prototypes for hydrology, sediment, and nutrients.**
  - **Operational prototypes with reasonable runtime and on the graph paper model results.**

Development Milestones (2022)

100K NHD	NHD-scale model structure; Hydrology prototype; Expanded simulation period 1985 to 2020; [1][2]
HYDROLOGY	Hydrology calibration (CalCAST→DWM) method updates; initial testing of numerical simplifications for flow routing; [3]
SEDIMENT	Sediment model; Hydrology model calibration updates with respect to stormflow; [4]
NUTRIENTS	Nutrient (Nitrogen and Phosphorus) model; Updated sediment model; [5]

[1] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/progress-in-phase-7-wsm-development-1.4.2022-gopal_bhatt_penn_state.pdf
[2] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/progress_in_phase_7_wsm_development_4.5.2022_-_gopal_bhatt_penn_state.pdf
[3] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/progress_in_phase_7_wsm_development_-_gopal_bhatt_penn_state_7.12.22.pdf
[4] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-10.4.22-v2.pdf
[5] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-1.10.2023.pdf

- **Year 2023: Incremental refinements of model prototypes in terms of model segmentation, CalCAST→DWM linkage, and simulation of the small streams.**

… incremental improvements during 2023

Segmentation	We performed re-segmentation and tested the revised model. ▪ tidal percent attribute was updated using new shoreline layer ▪ all databases (river mainstem, topology, etc.) were updated ▪ segmentations in the tidal watershed were improved
Model	Improvements on overcoming the 'aggregation effect' in the simulation of river mainstems (CalCAST → DWM) ➢ Non-iterative hydraulic routing for small 100K NHDplus streams ➢ WQ routing (TN) for small 100K NHDplus streams
Simulation	Testing on Amazon AWS and MS Azure cloud HPC environments with various node type and size configurations

[1] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/20230404-BHATT-Phase-7-WSM-Development-Dynamic-Model-Development-2023Q1.pdf
[2] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-6.20.2023.pdf
[3] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-10.17.2023.pdf
[4] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/20240109-BHATT-Phase-7-WSM-Development-Dynamic-Model-Development-2023Q4.pdf

- **Year 2024 Q1: small stream routing based on β parameters**

[1] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-CBPO-4.2.2024.pdf

Water Quality Calibration

Step 1: mechanics of water quality calibration

- We implemented a draft of the calibration framework through development of scripts according to P7 modules and data flow.

- We tested the calibration framework by running it for two model setups:
    1. Output = Input x stream transport factor [Output = Input x STF]
    2. Small stream routing for flow and water quality [Beta Parameters]

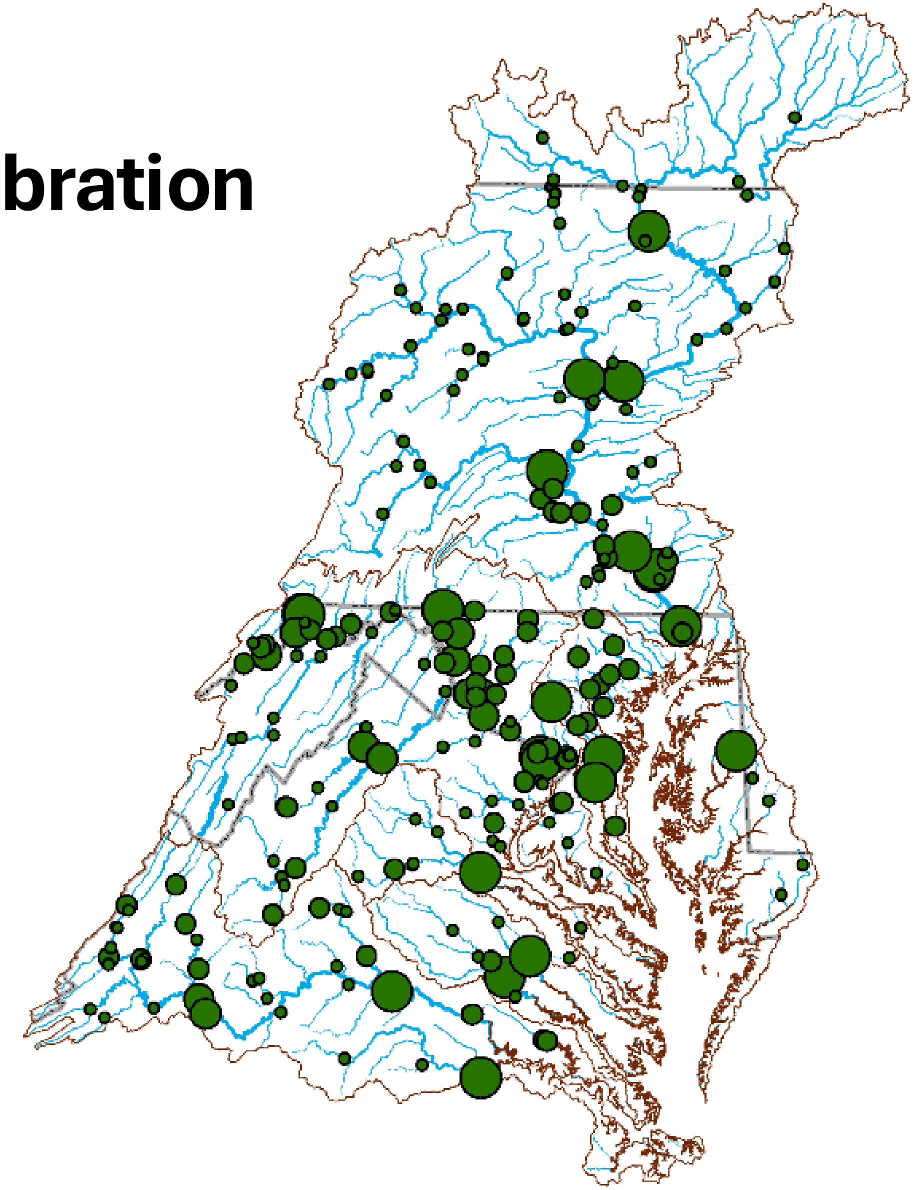
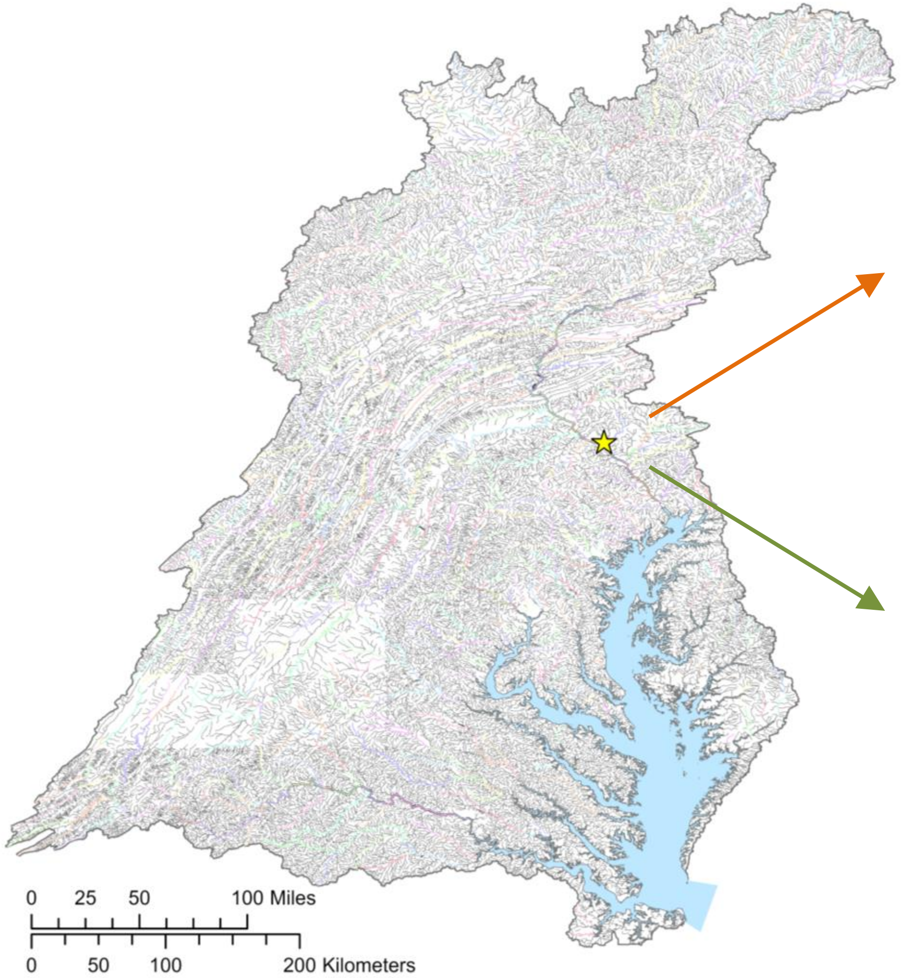
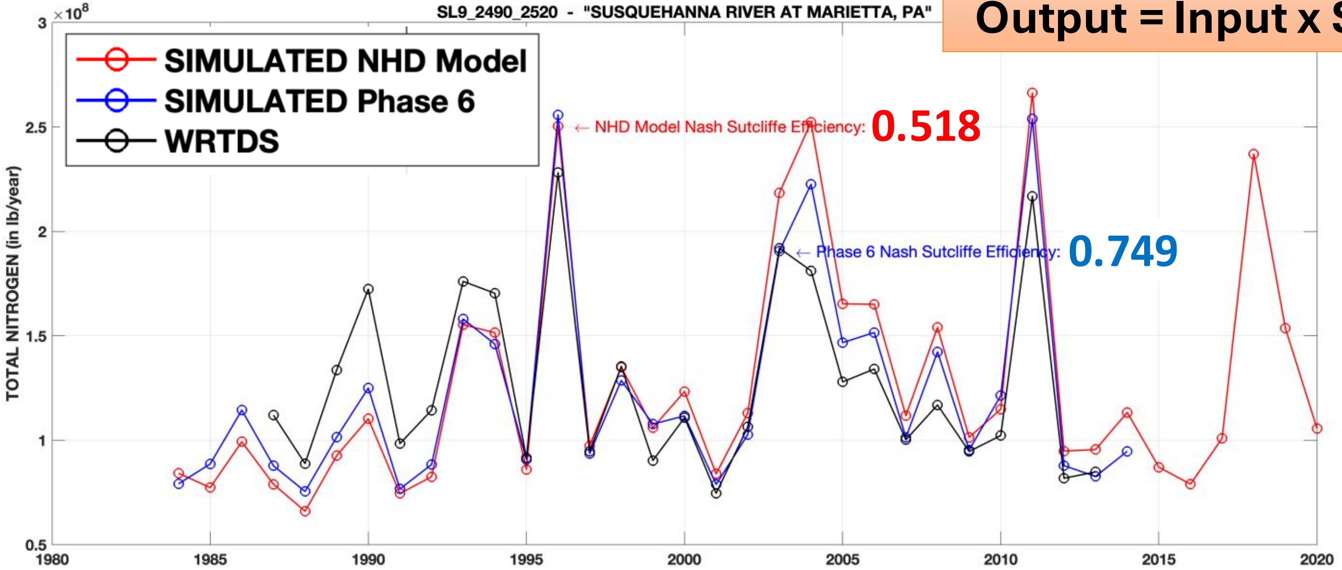


Figure: Monitoring stations used in the model calibration. Number of samples of total nitrogen are shown.

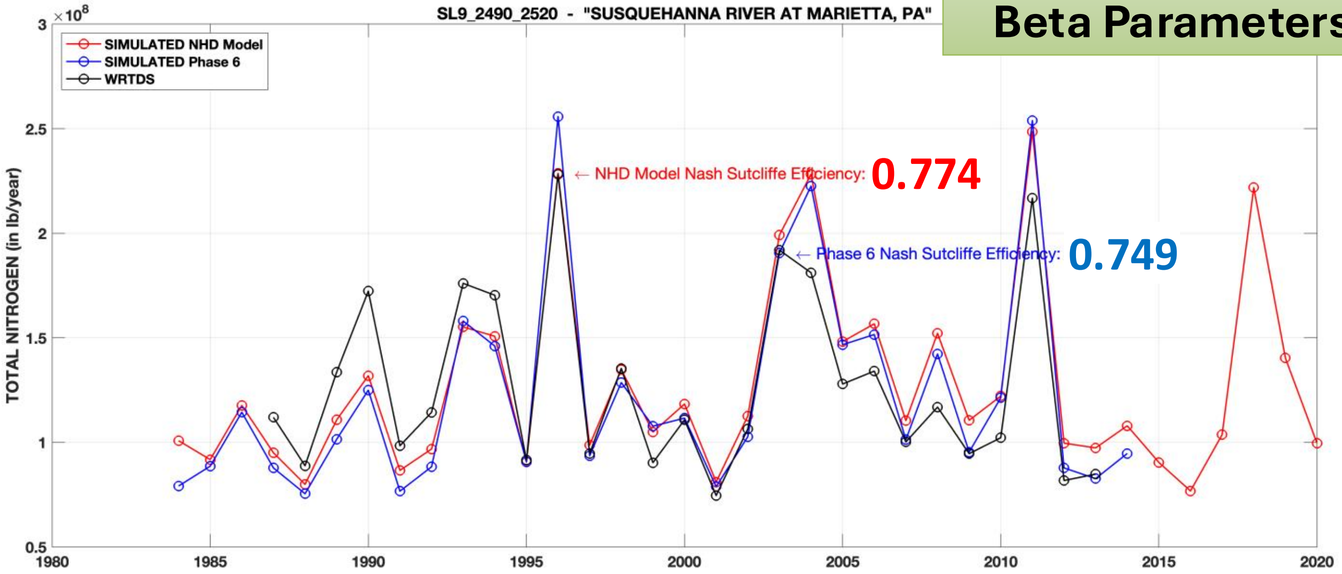
Nitrogen – P6 Parameters



Output = Input x STF

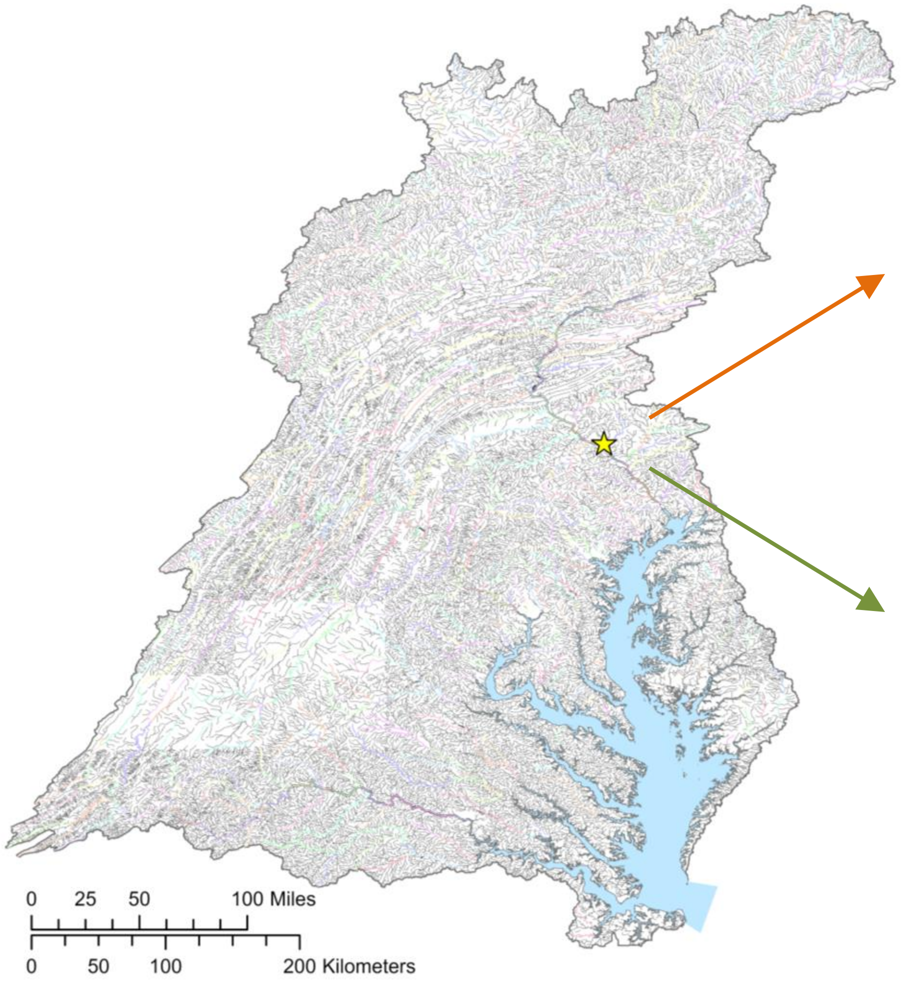


Beta Parameters[1]

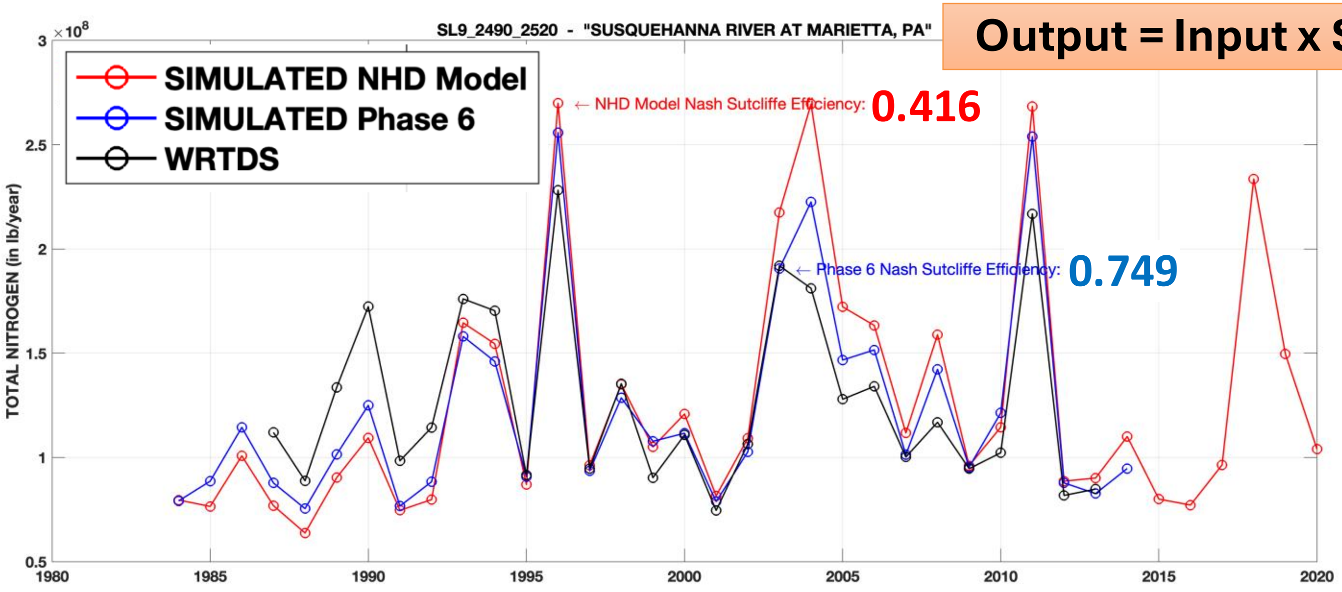


[1] Watershed average beta parameters for all streams

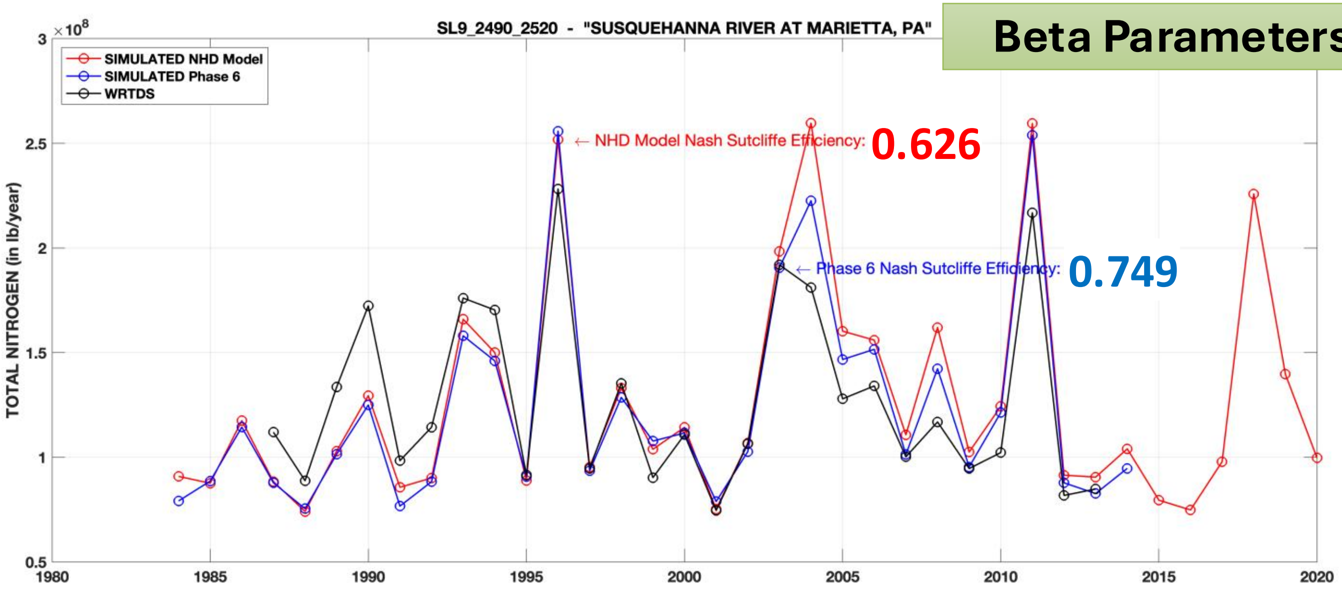
Nitrogen – P7 Calibration[2]



Output = Input x STF



Beta Parameters[1]

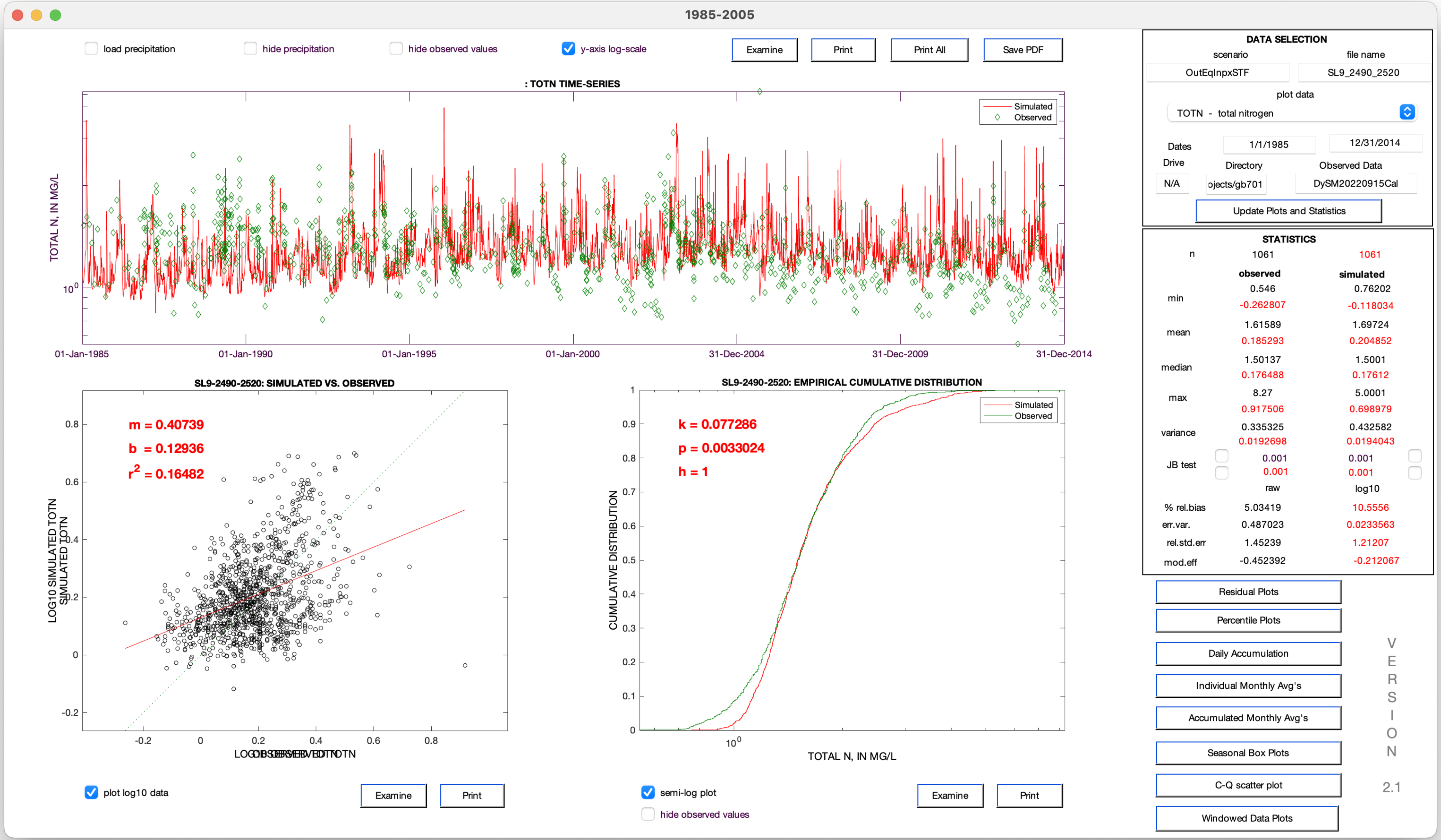


[1] Watershed average beta parameters for all streams
[2] initial drafting and testing of calibration mechanics only

Output = Input x STF

Susquehanna at Marietta

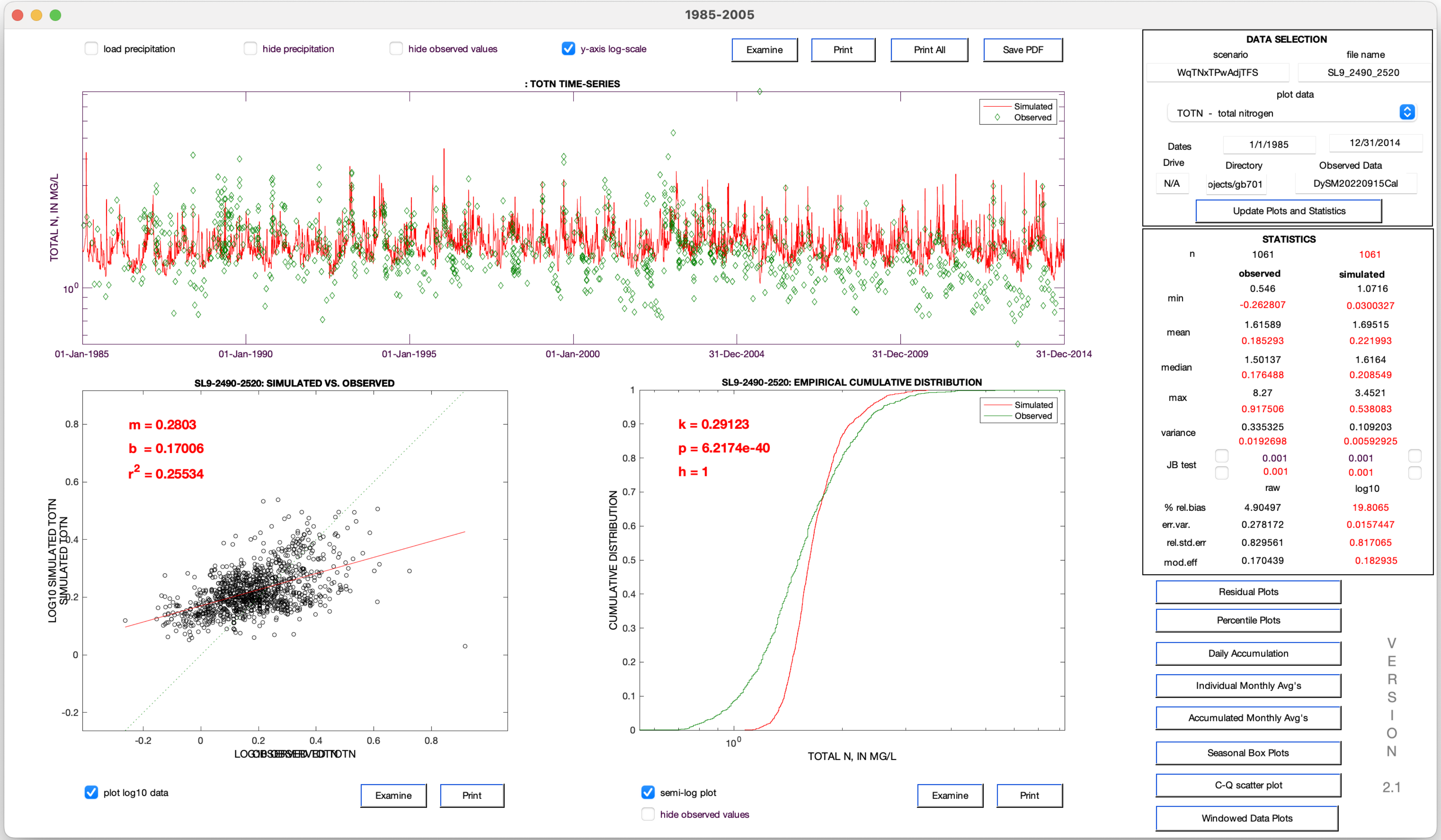
Nitrogen



Beta Parameters

Susquehanna at Marietta

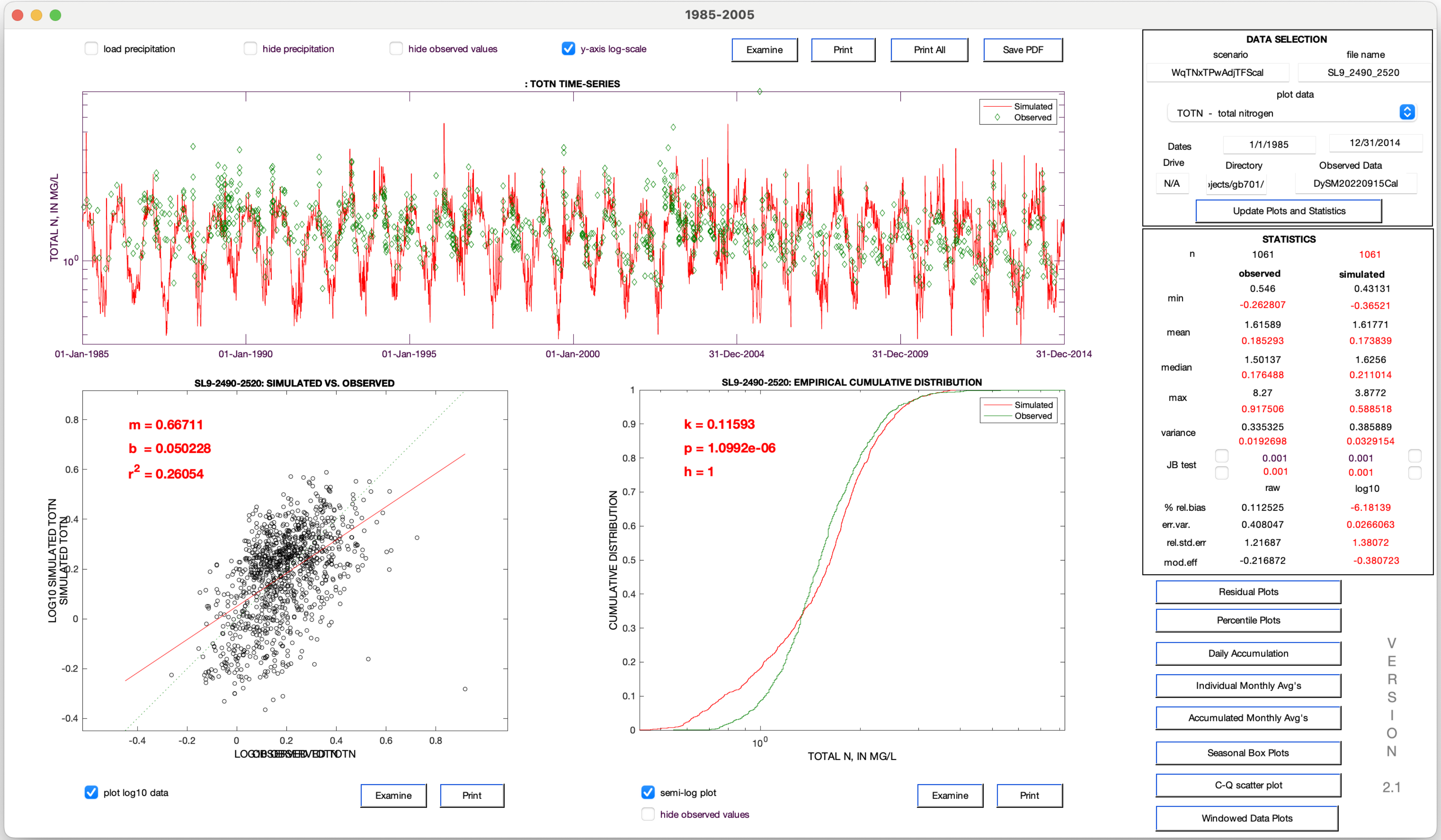
Nitrogen



βs with calibration

Susquehanna at Marietta

Nitrogen



Step 2: revisions to the calibration methods (2024 Q3)

Information available for the calibration dynamic model parameters:

- **Observations of daily concentrations for nutrient species at monitoring stations**
- **Transport factors for TN, TP, and SS for each river mainstems (CalCAST)**
- **QC relationships (generalized *β* parameters for river mainstems)**

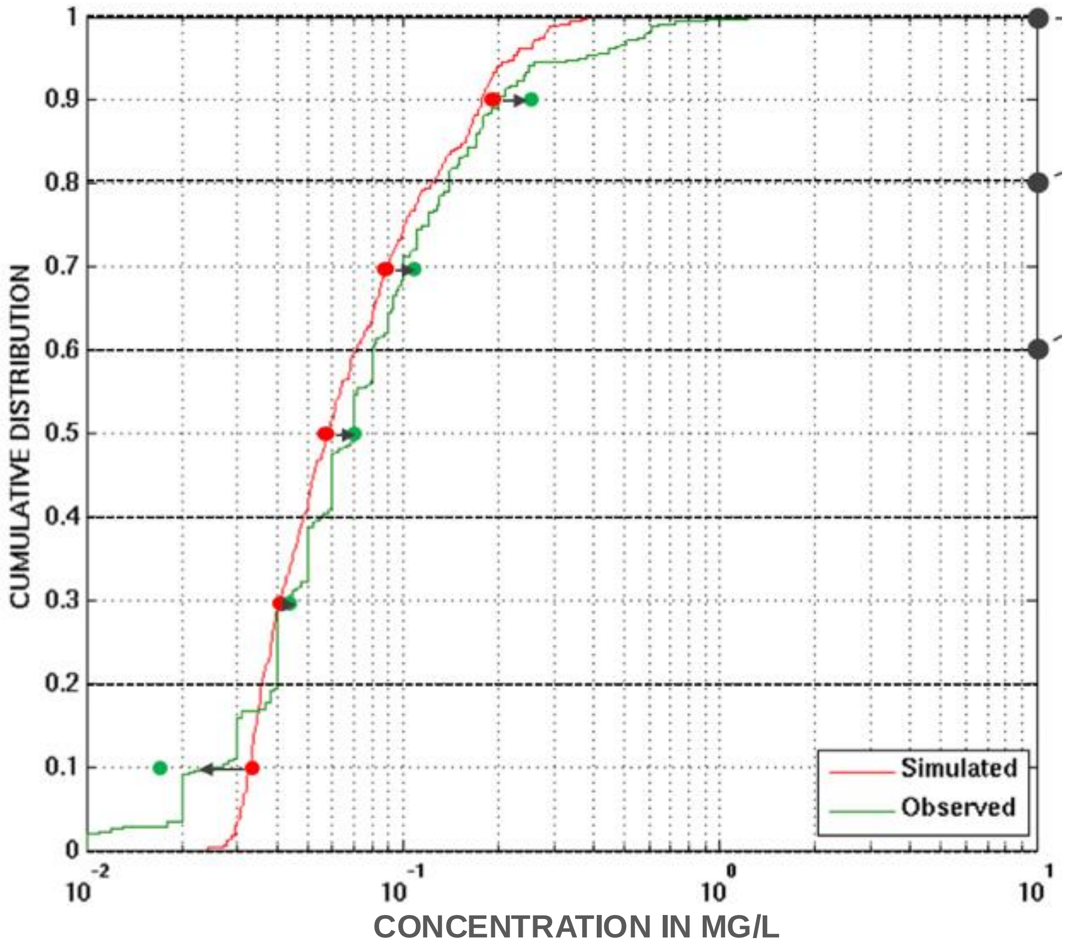
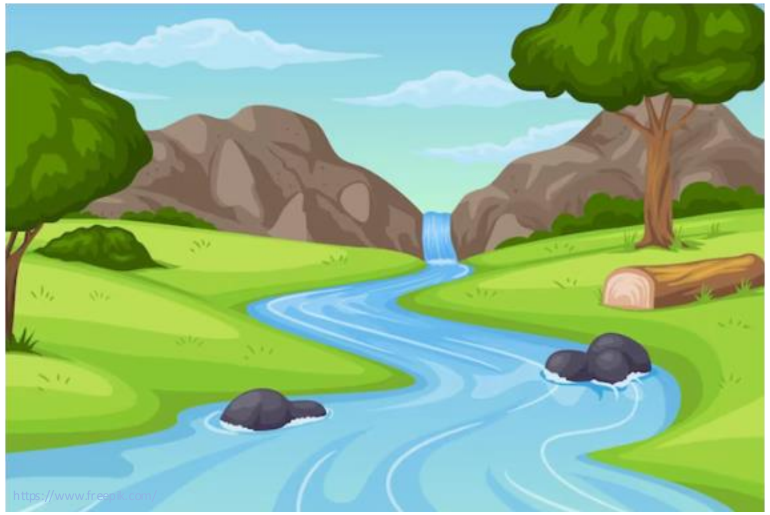


Figure: Cumulative distribution of concentrations at a monitoring station.

Small-stream flow and concentration (Q-C) relationship

HSPF: hourly surface and groundwater hydrology of land uses

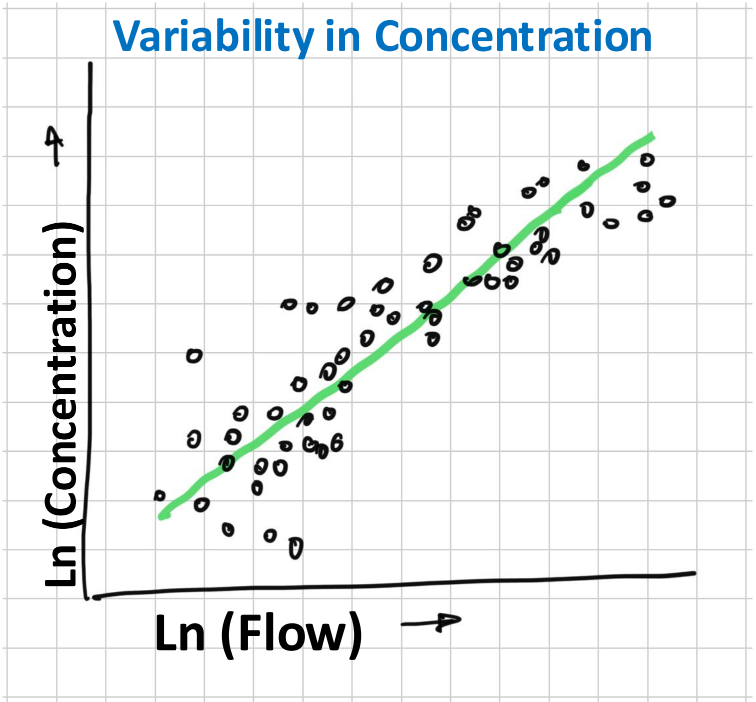
UNEC: annual surface and groundwater concentrations as a function of input history and estimates of lag-times



Biogeochemical processing, Storage/deposition, Scour
➔ Fate and Transport

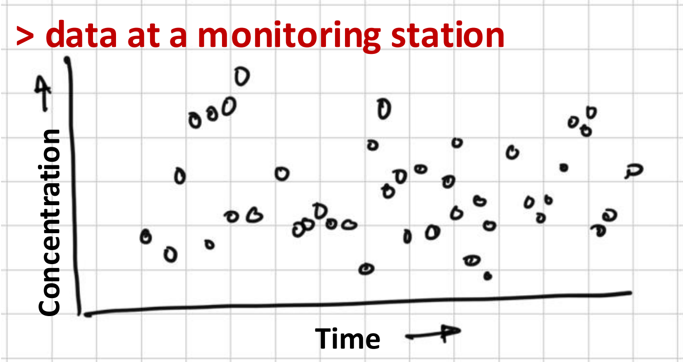
? ... emergent behavior

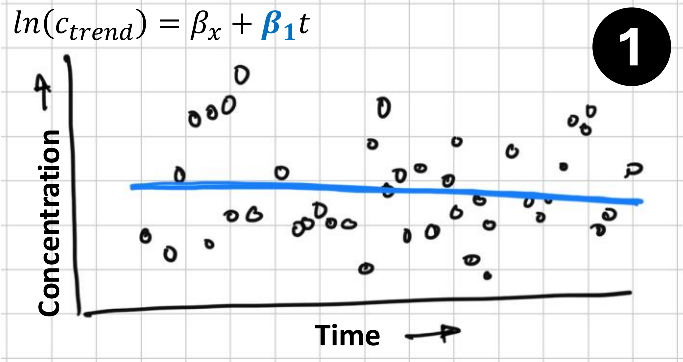
Stream Transport Factor (STF)

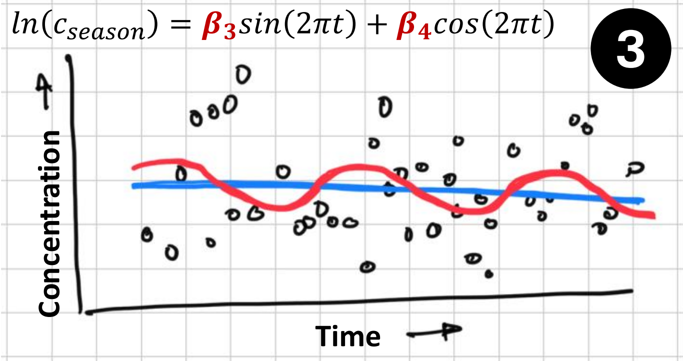


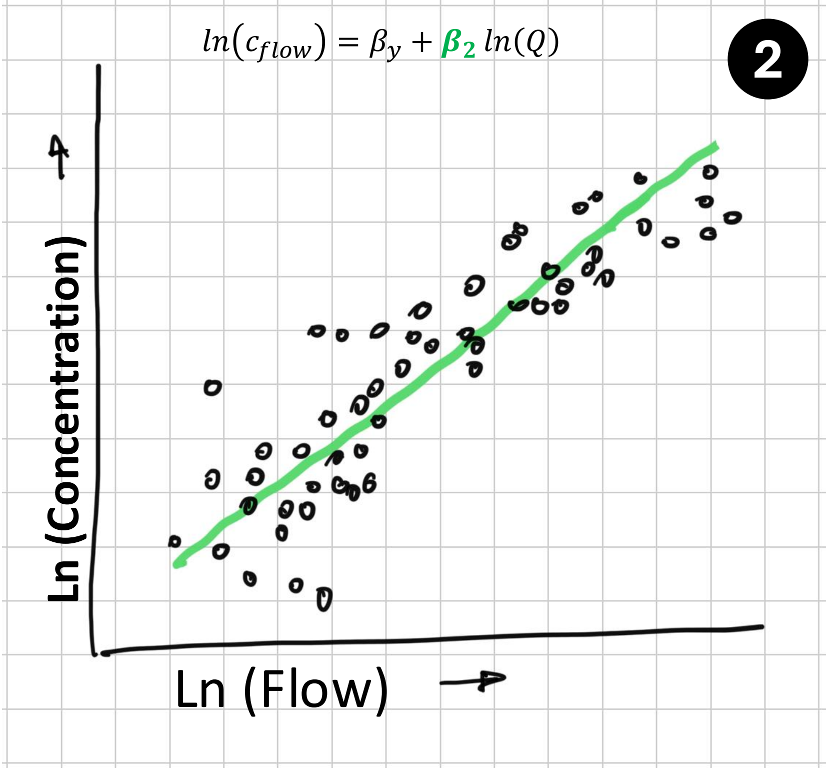
Small-stream flow and concentration (Q-C) relationship

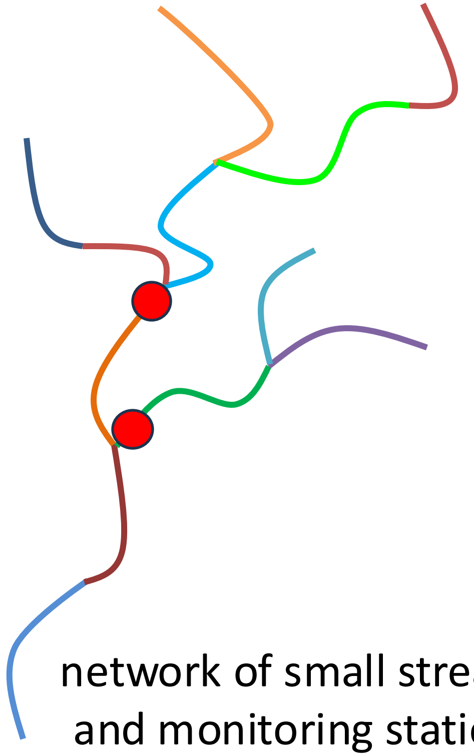
$$ln(c) = \beta_o + \underbrace{\beta_1 t}_{1} + \underbrace{\boldsymbol{\beta_2}\, ln(Q)}_{2} + \underbrace{\boldsymbol{\beta_3} sin(2\pi t) + \boldsymbol{\beta_4} cos(2\pi t)}_{3} + \varepsilon$$





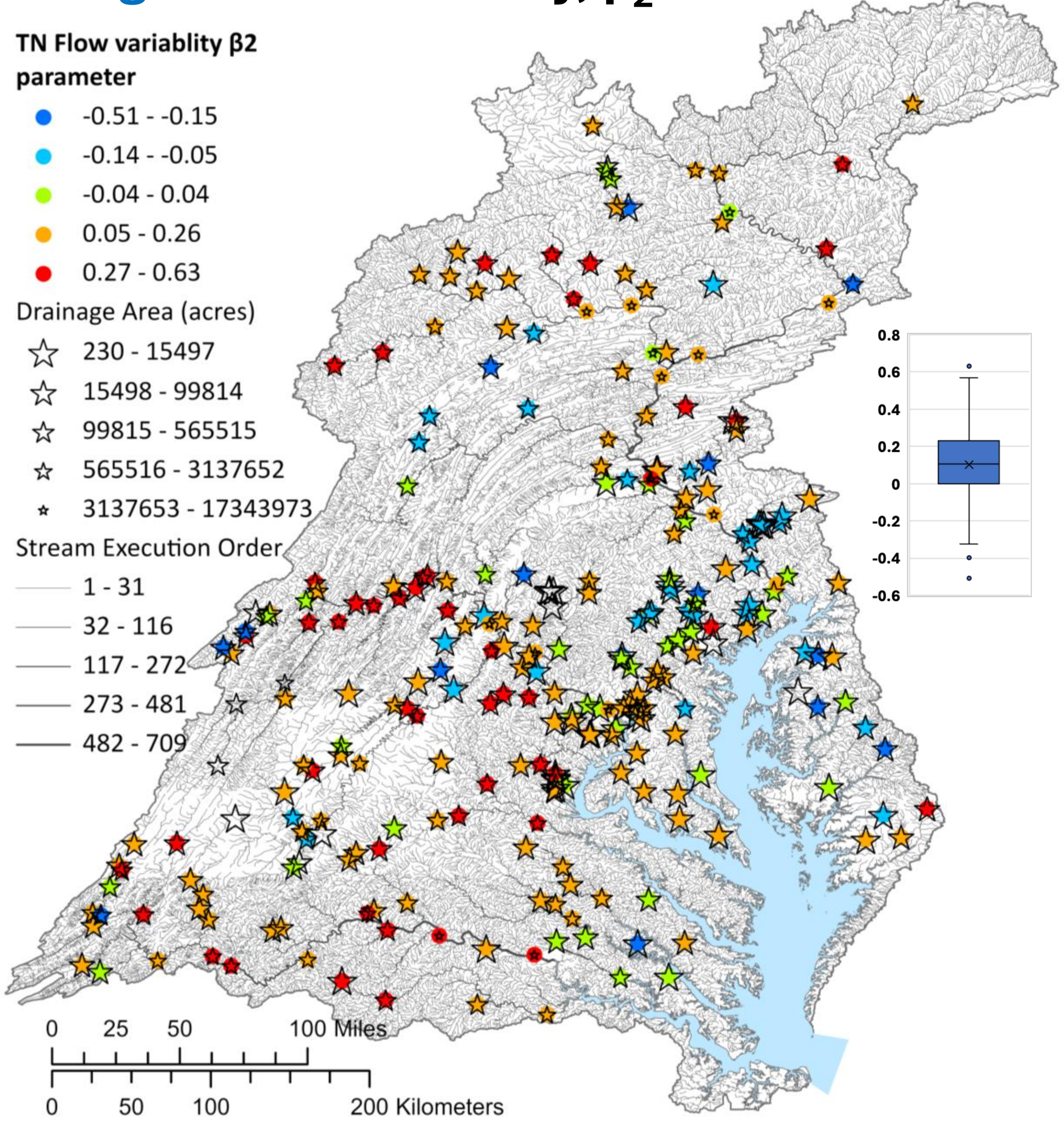




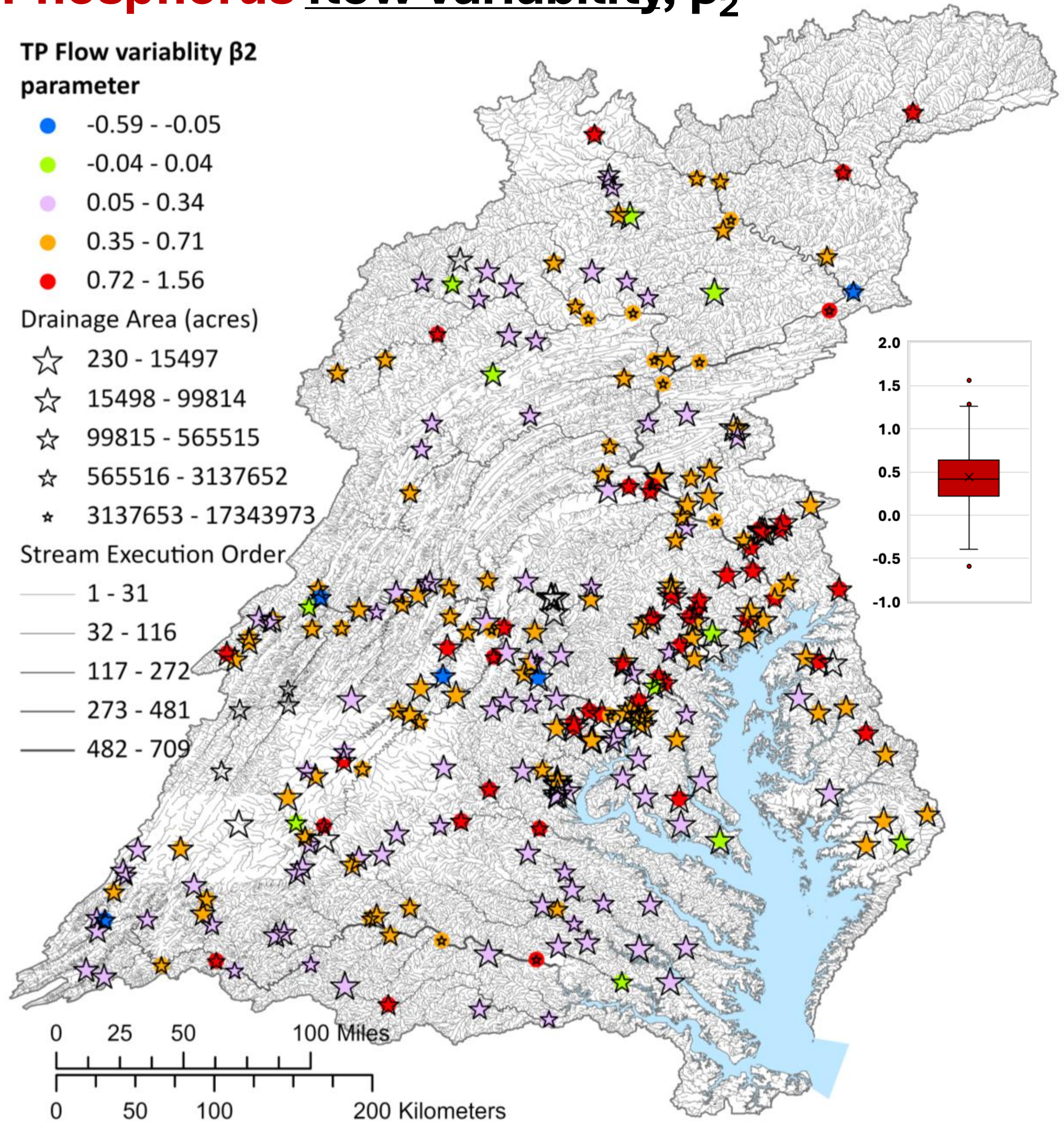


network of small streams and monitoring stations with water quality and streamflow data

Nitrogen flow variability, β_2



Phosphorus flow variability, β_2

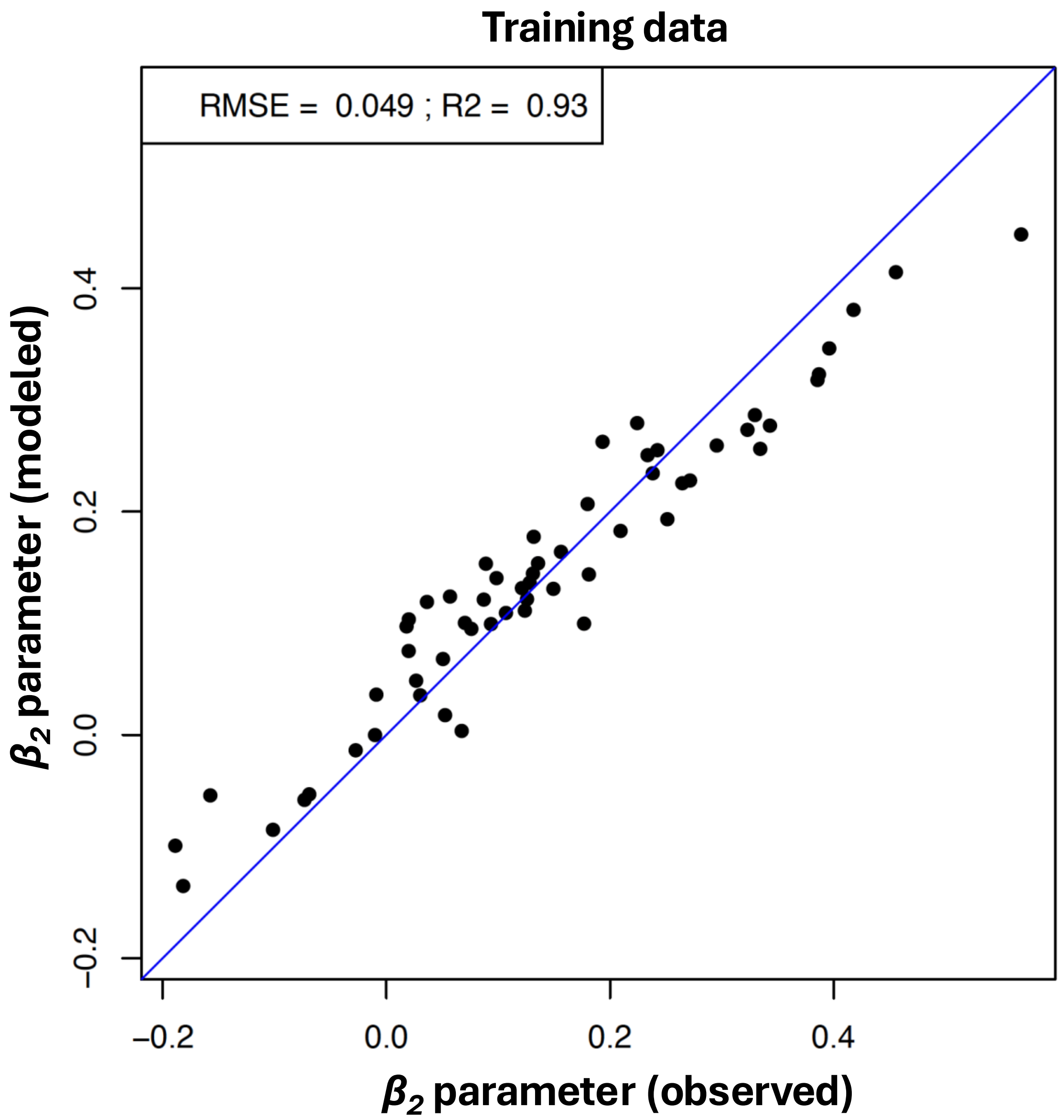


$$ln(c) = \beta_o + \beta_1 t + \boldsymbol{\beta_2}\, ln(Q) + \beta_3 sin(2\pi t) + \beta_4 cos(2\pi t) + \varepsilon$$

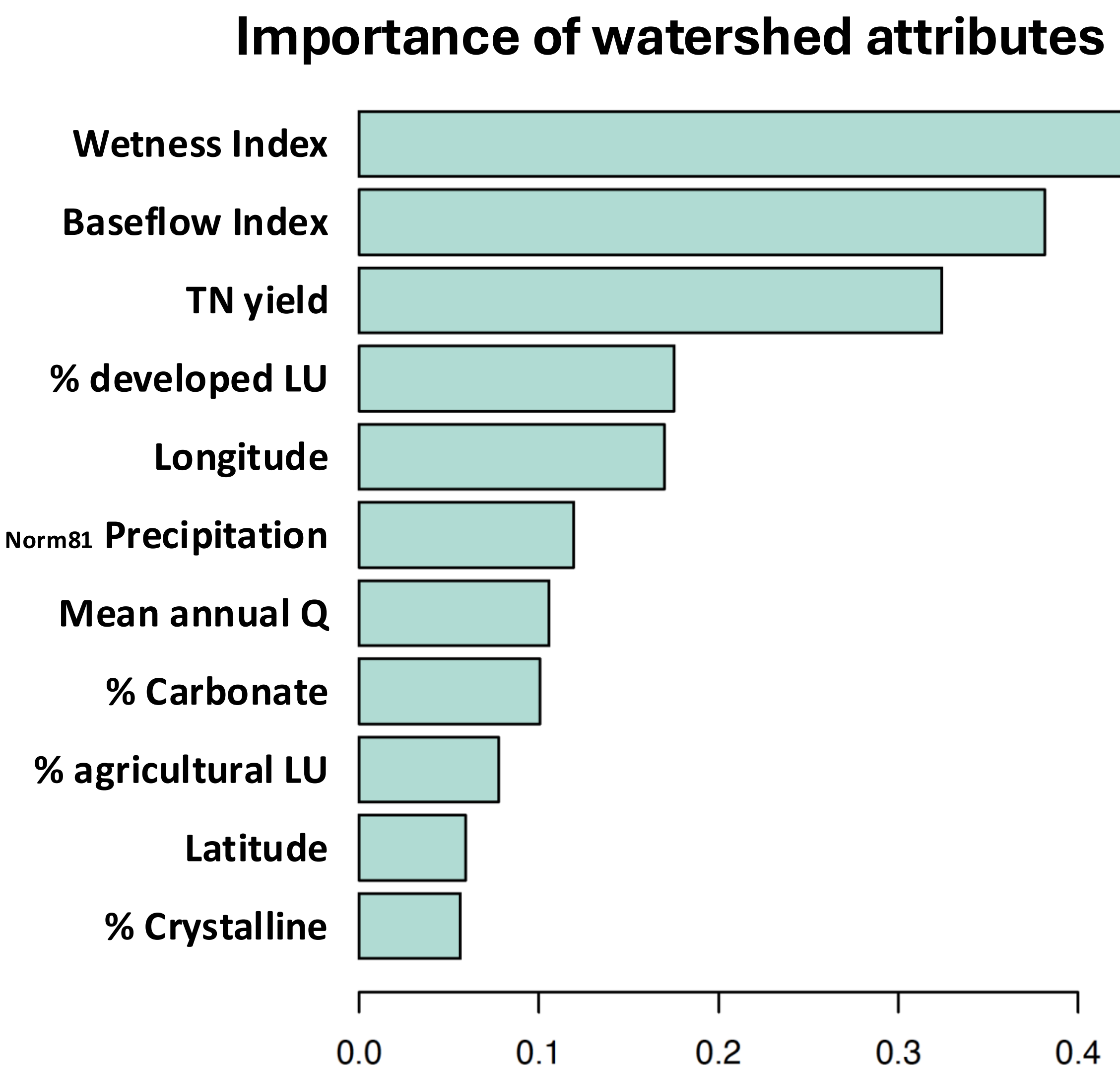
Generalization of β parameters – Qian Zhang

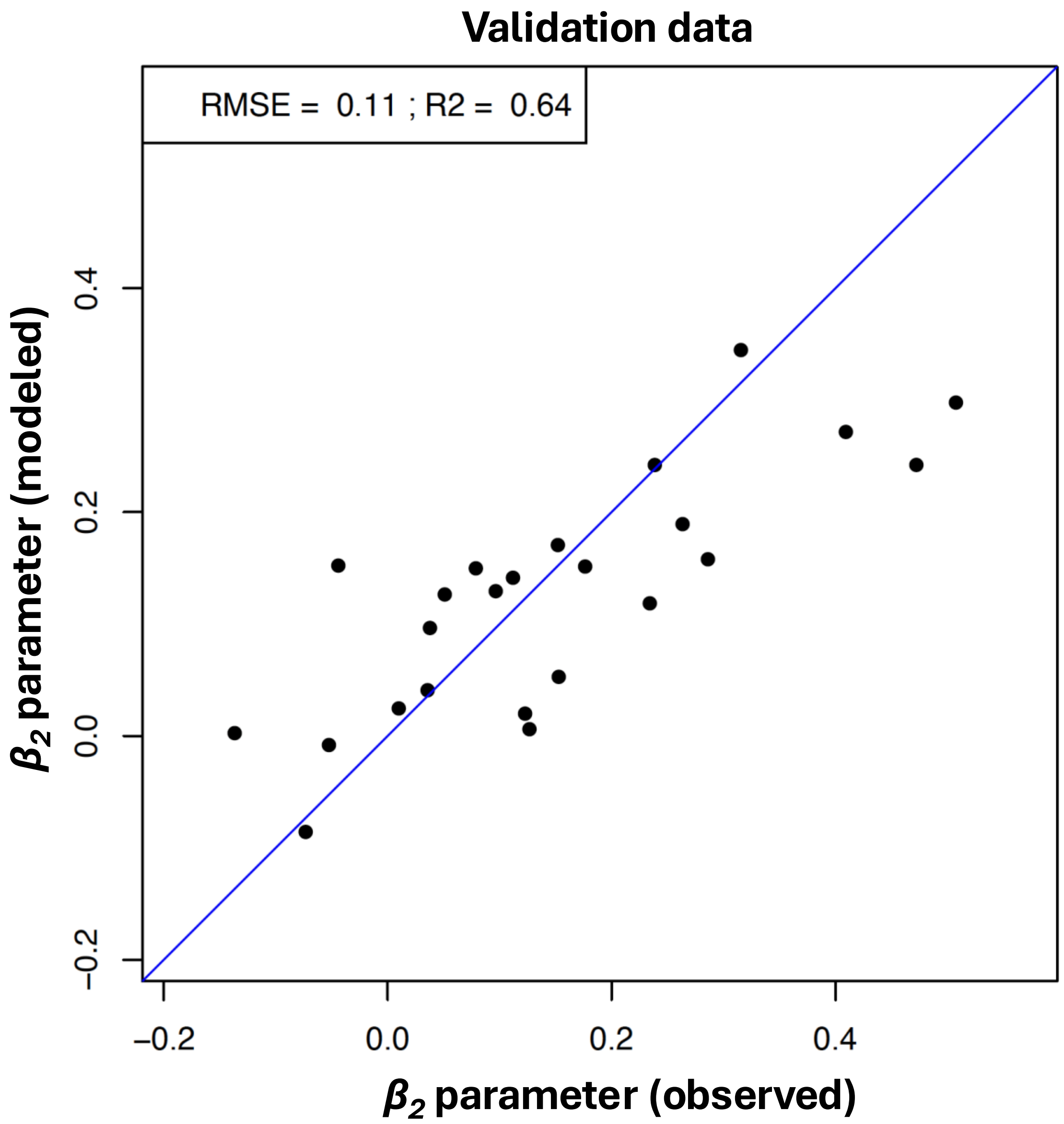
An <u>initial</u> *Random Forest* model was developed:

- **The model links β_2 parameter with watershed attributes**
- **Performance of the model for training data is shown in the figure**
- **Currently using data for NTN stations; an expansion would require watershed attributes for additional stations**



Generalization of β parameters – Qian Zhang





Summary

1. We are focusing our efforts on water quality calibration for linking watershed model flows and loads with the estuarine model

- we successfully implemented and tested Step 1 covering mechanics of water quality calibrations
- over the next quarter we will work on revisions to the calibration methods (Step 2)

2. Initial model for the generalization of β_2 parameter for TN performed quite well. But it needs additional work for improving the model, including use of relevant explanatory variables.

>> Next Steps for the Phase 7 Dynamic Watershed Model (DWM)

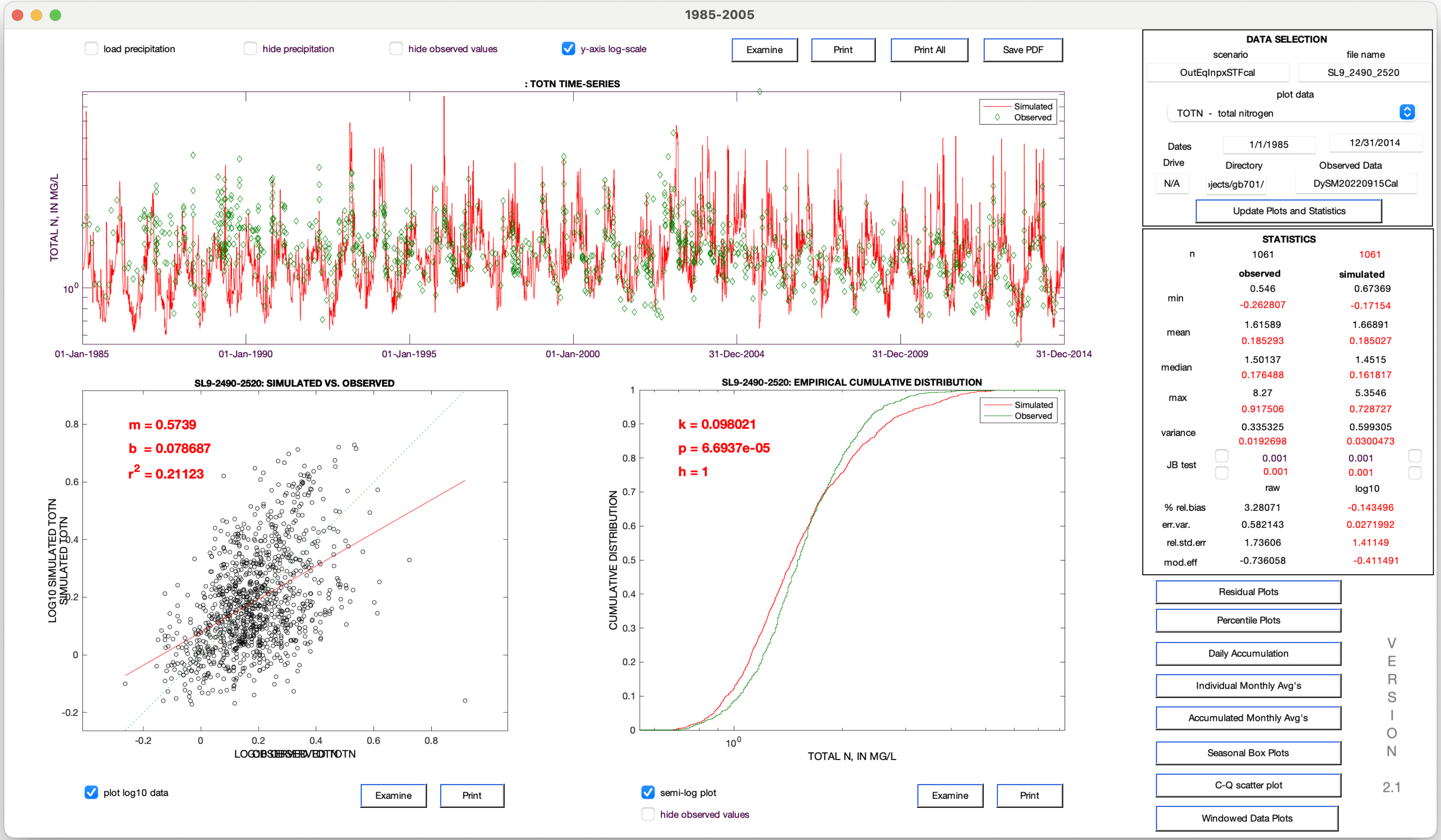
3. (a) Testing and revisions to calibration methods, and (b) incorporation of new data where appropriate.

Plots comparing the calibration of both (a) Output = Input x stream transport factor (STF) vs. (b) Small-stream routing for flow and water quality

Out=Inp x STF with calibration

Susquehanna at Marietta

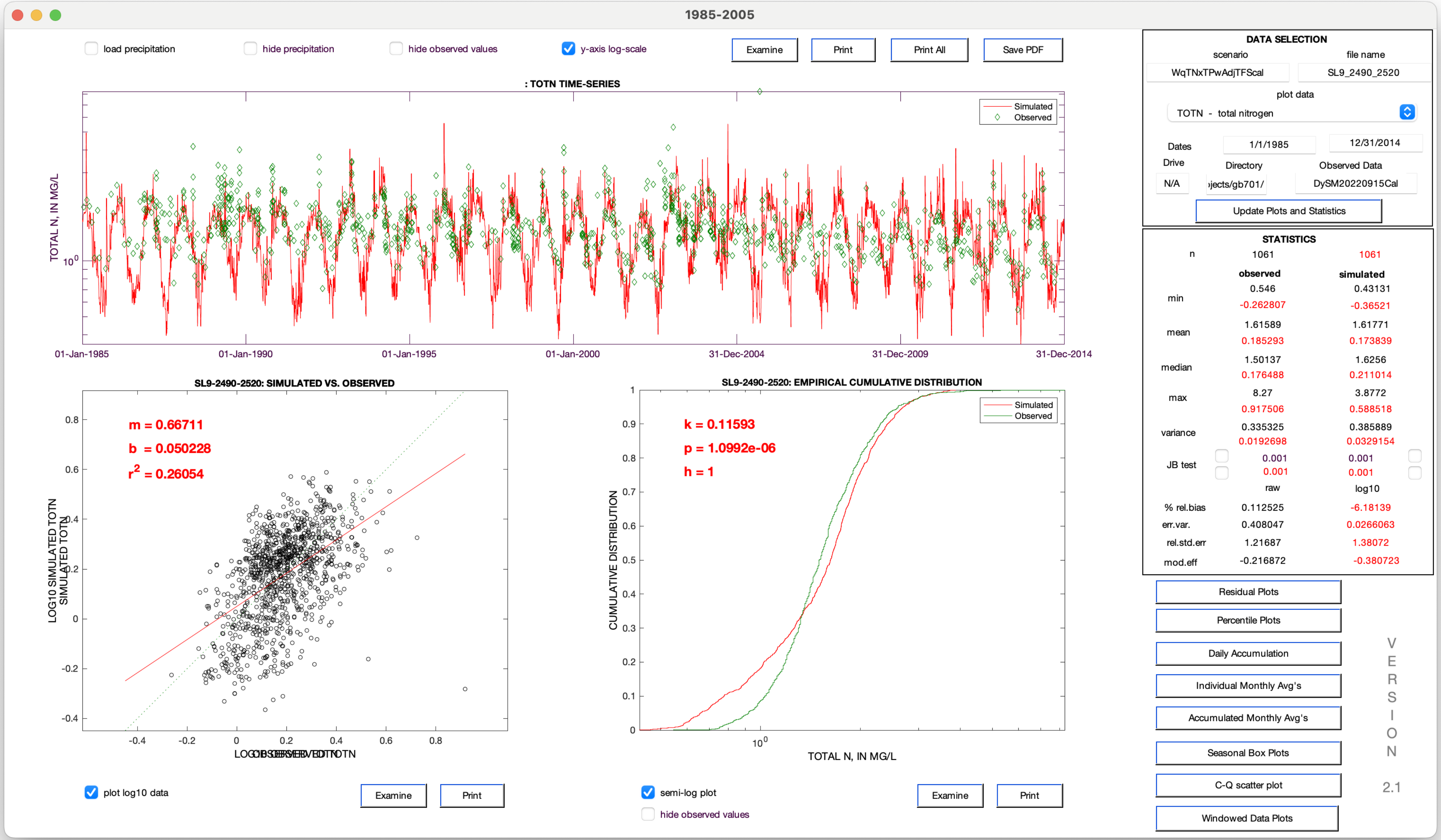
Nitrogen



βs with calibration

Susquehanna at Marietta

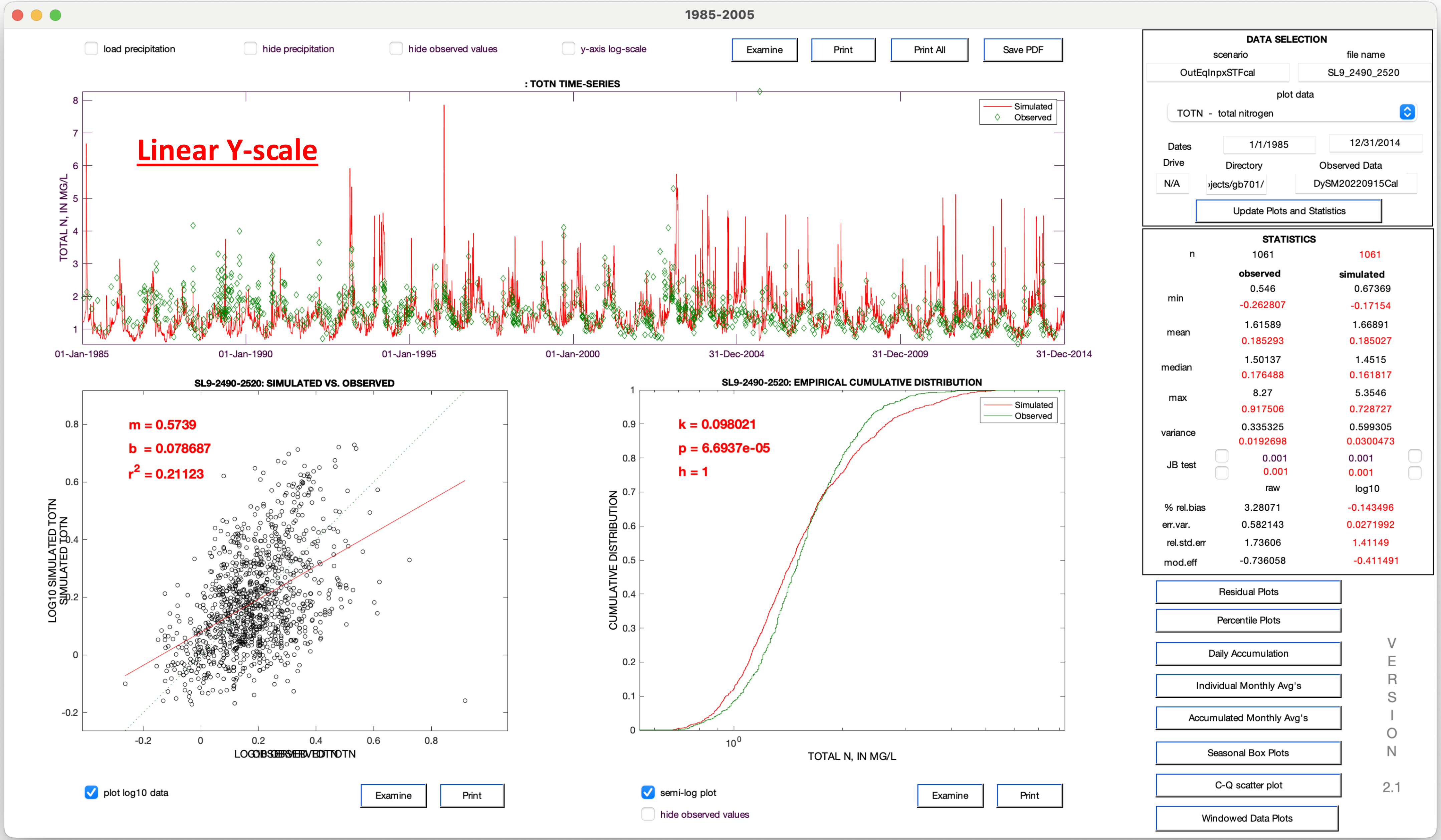
Nitrogen



Out=Inp x STF with calibration

Susquehanna at Marietta

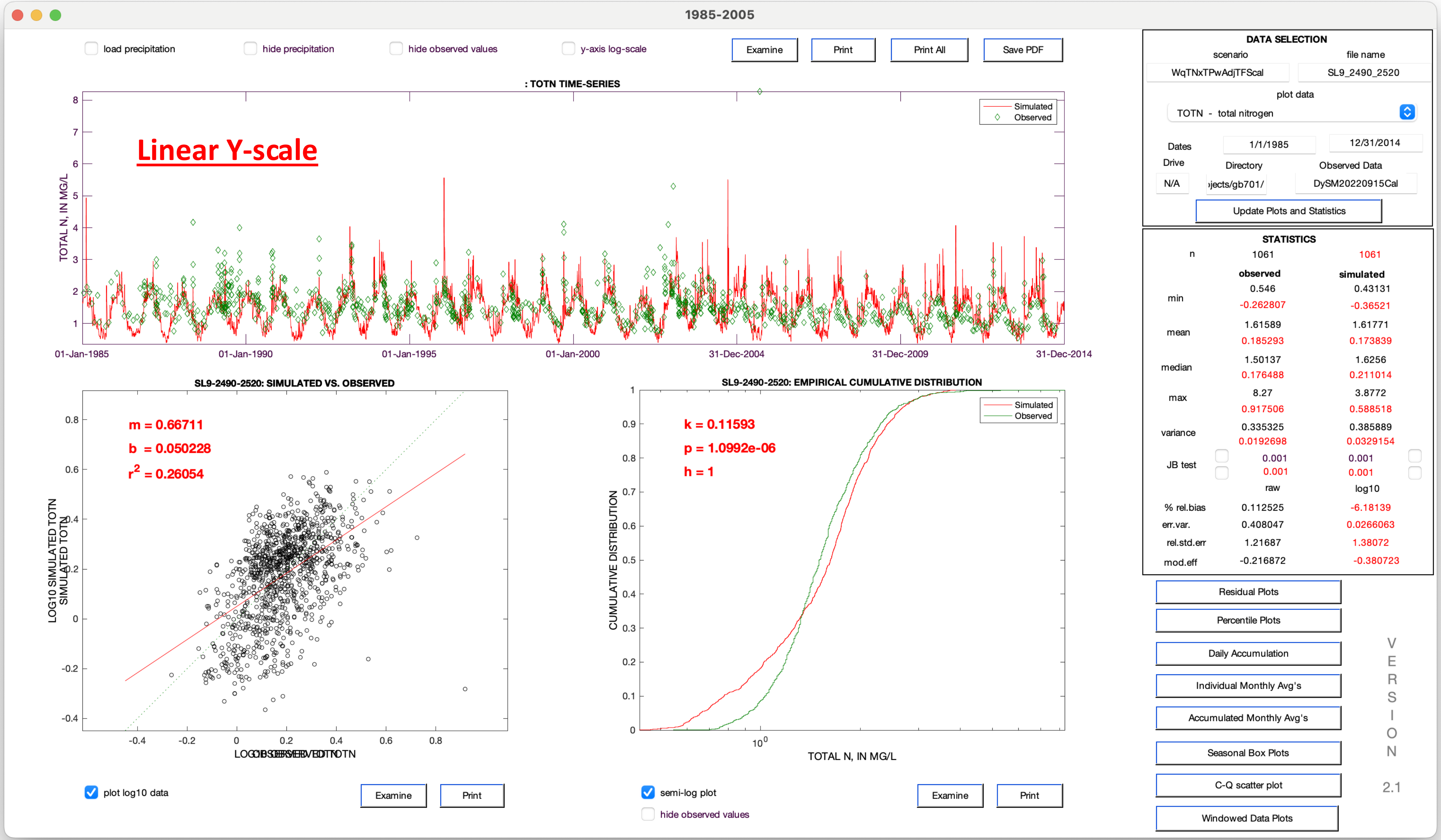
Nitrogen



βs with calibration

Susquehanna at Marietta

Nitrogen

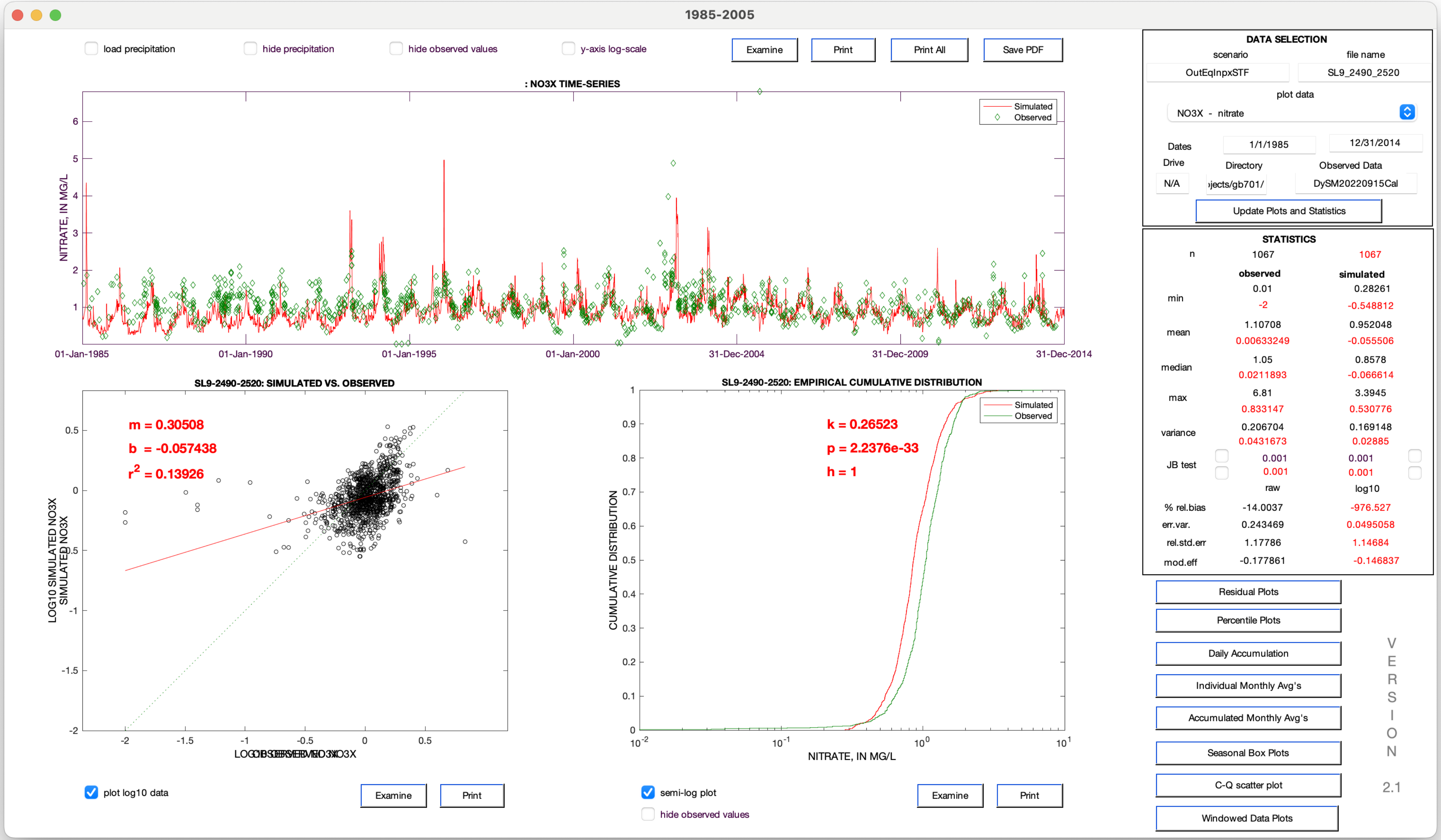


Calibration plots for the nitrate (before and after calibration)

Output = Input x STF

Susquehanna at Marietta

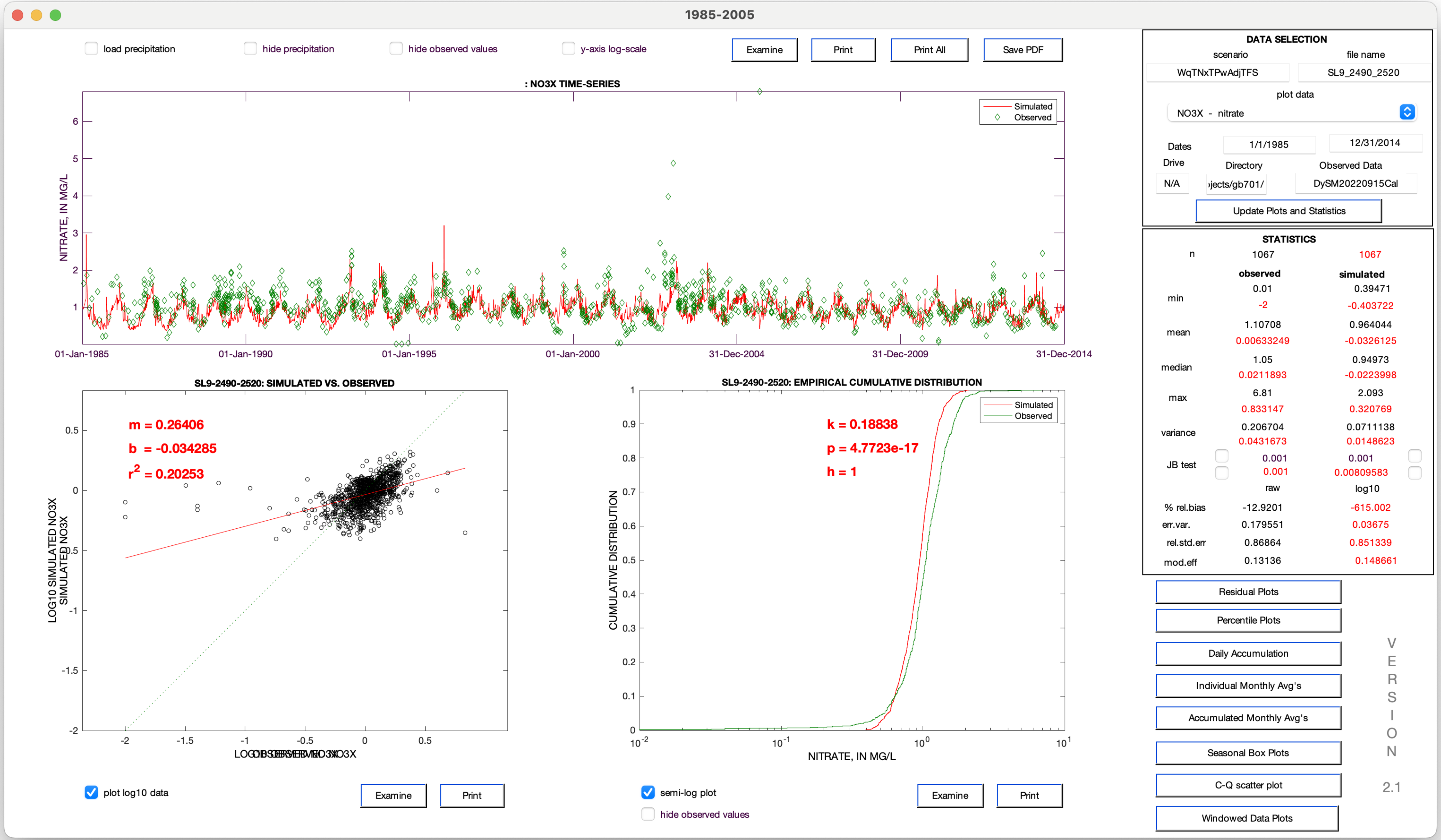
Nitrate



Beta Parameters

Susquehanna at Marietta

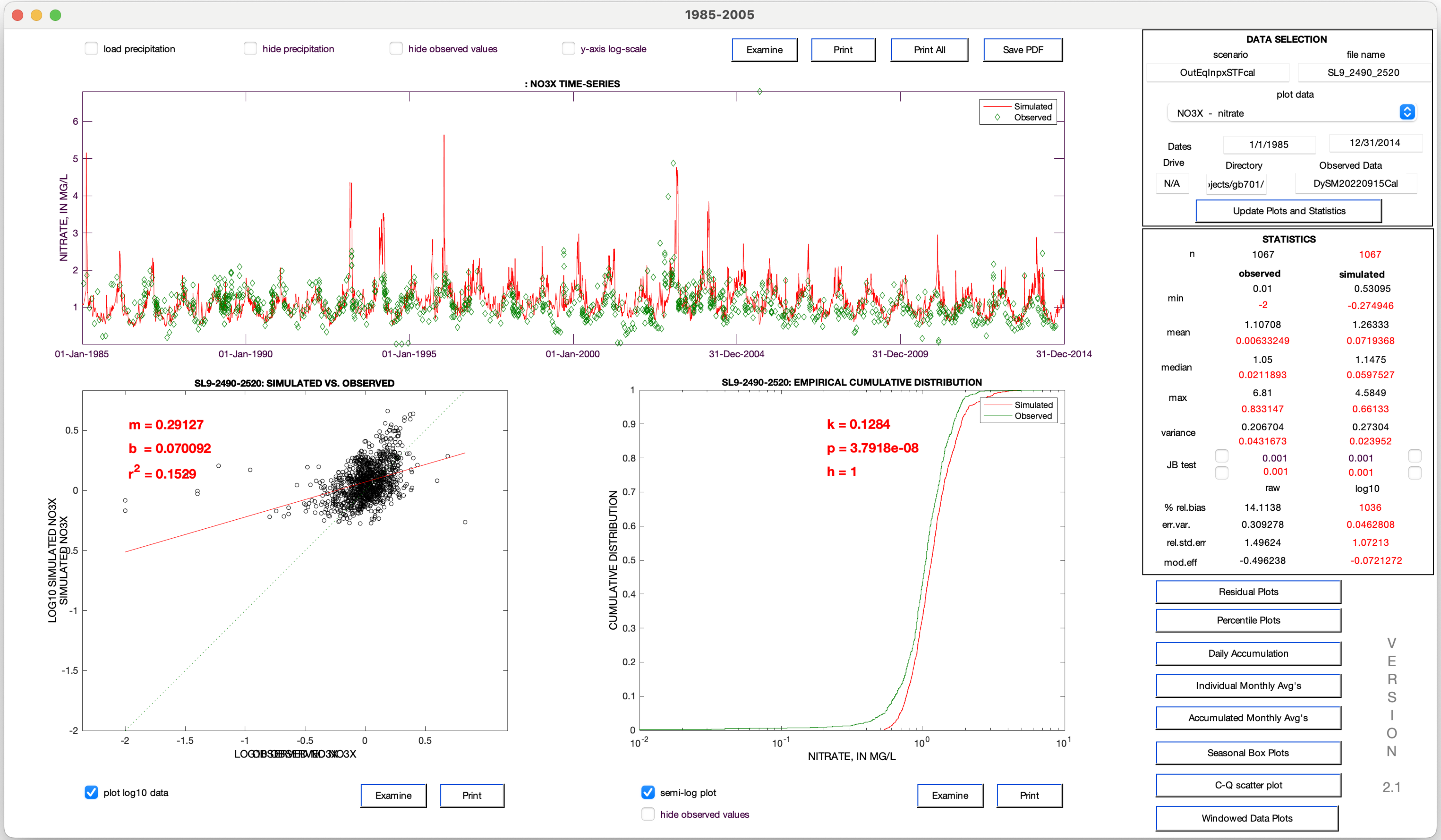
Nitrate



Out=Inp x STF with calibration

Susquehanna at Marietta

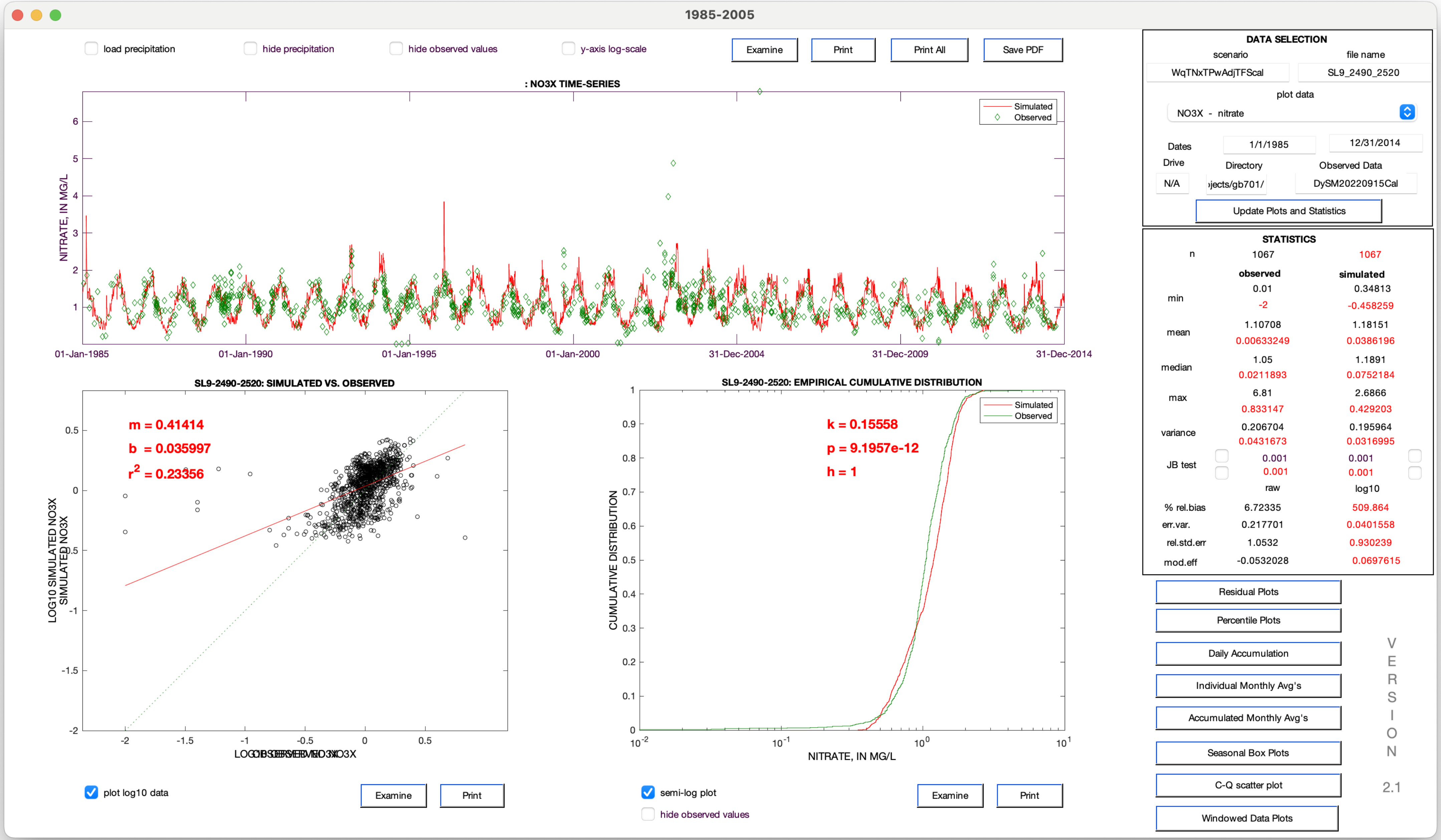
Nitrate



βs with calibration

Susquehanna at Marietta

Nitrate

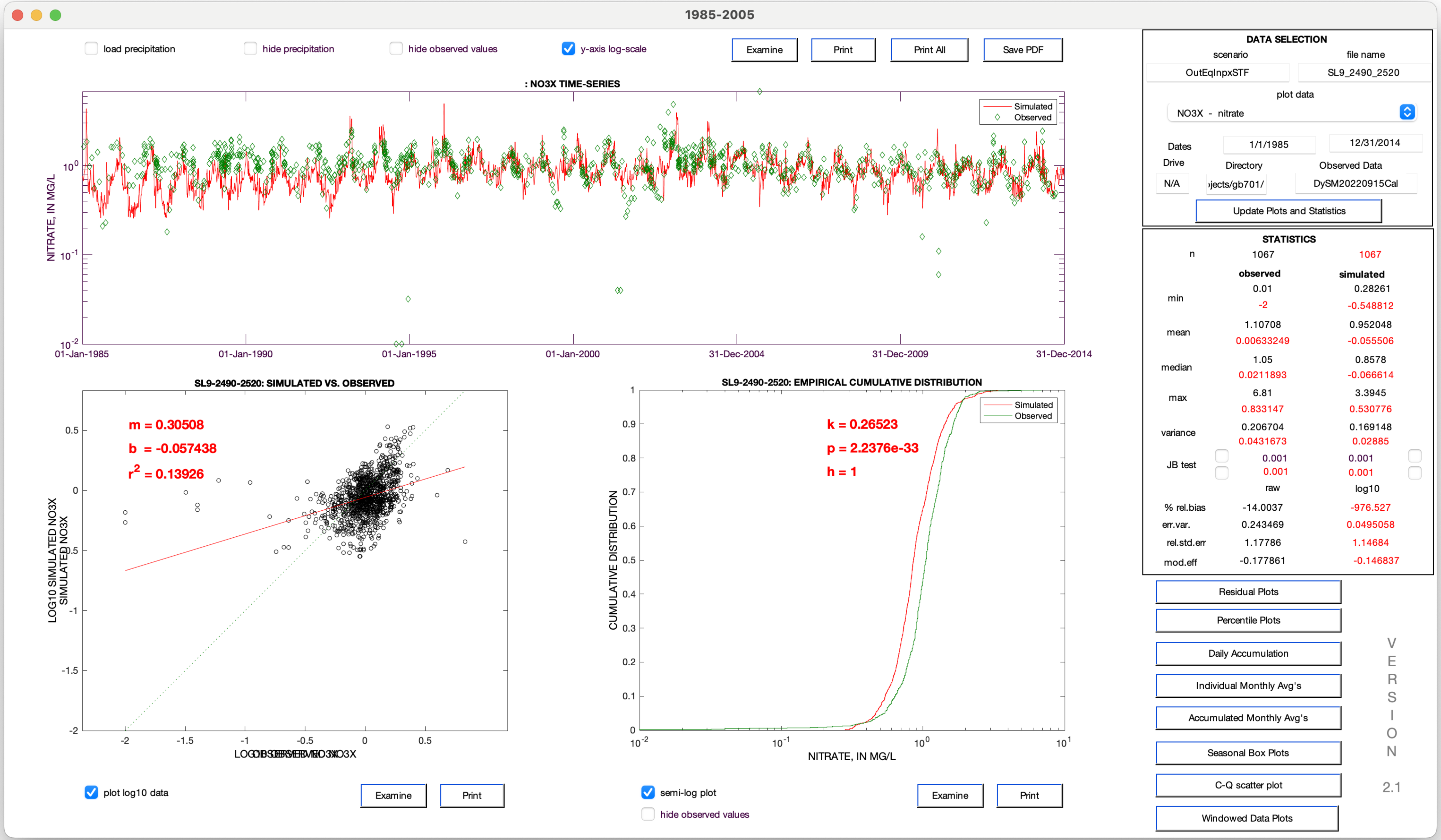


Calibration plots for the nitrate (before and after calibration)

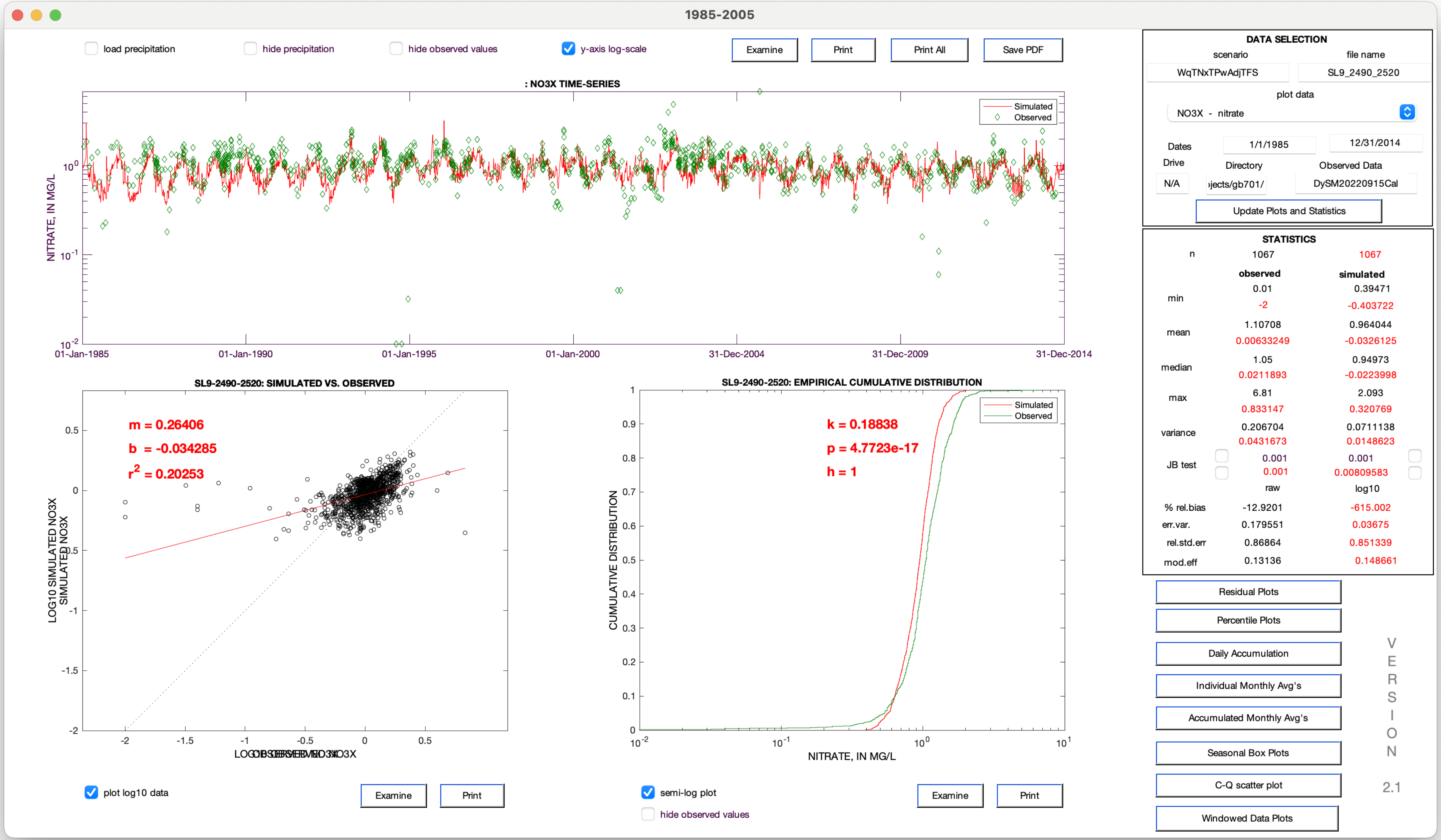
Output = Input x STF

Susquehanna at Marietta

Nitrate



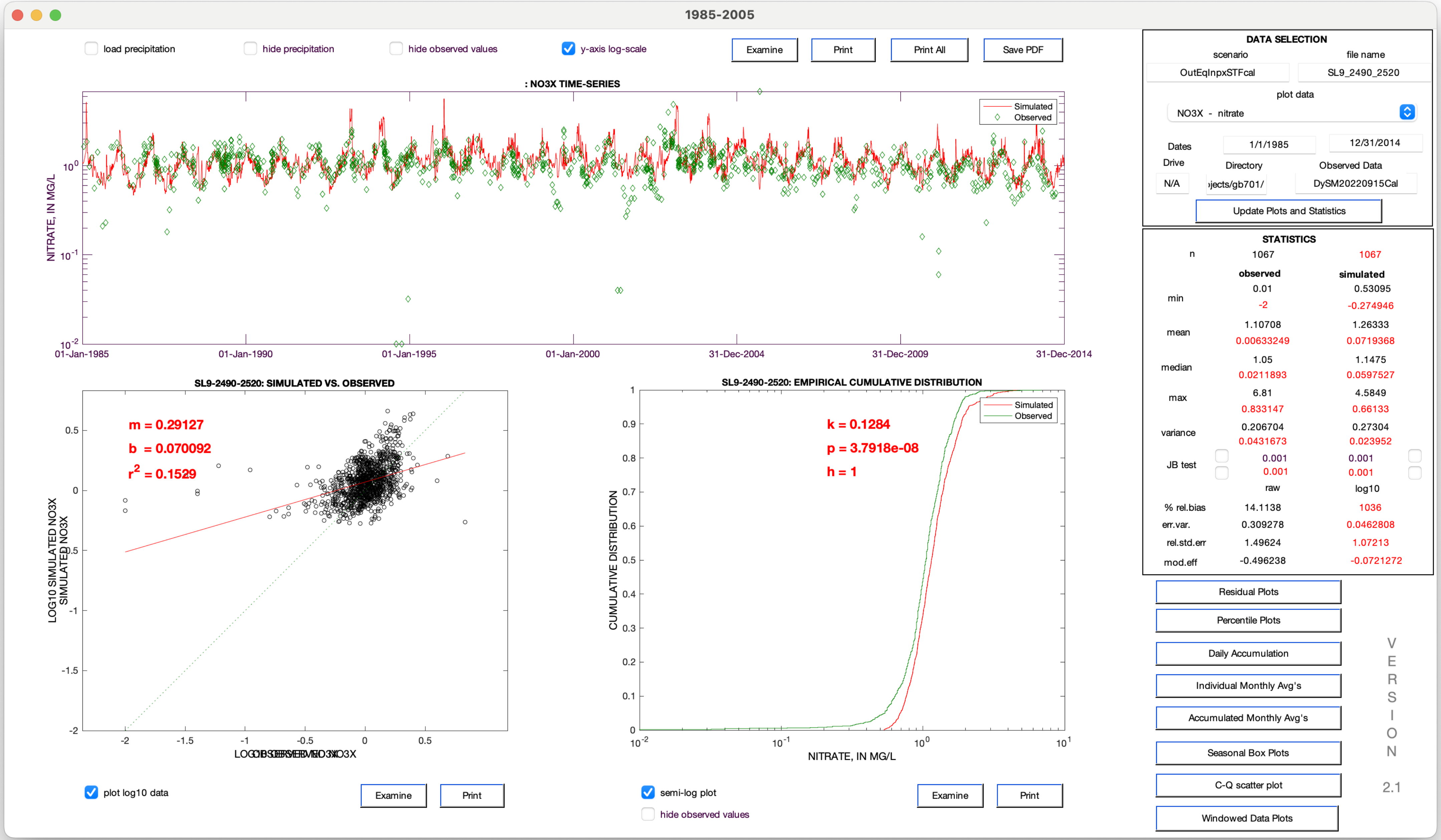
Beta Parameters | **Susquehanna at Marietta** | **Nitrate**



Out=Inp x STF with calibration

Susquehanna at Marietta

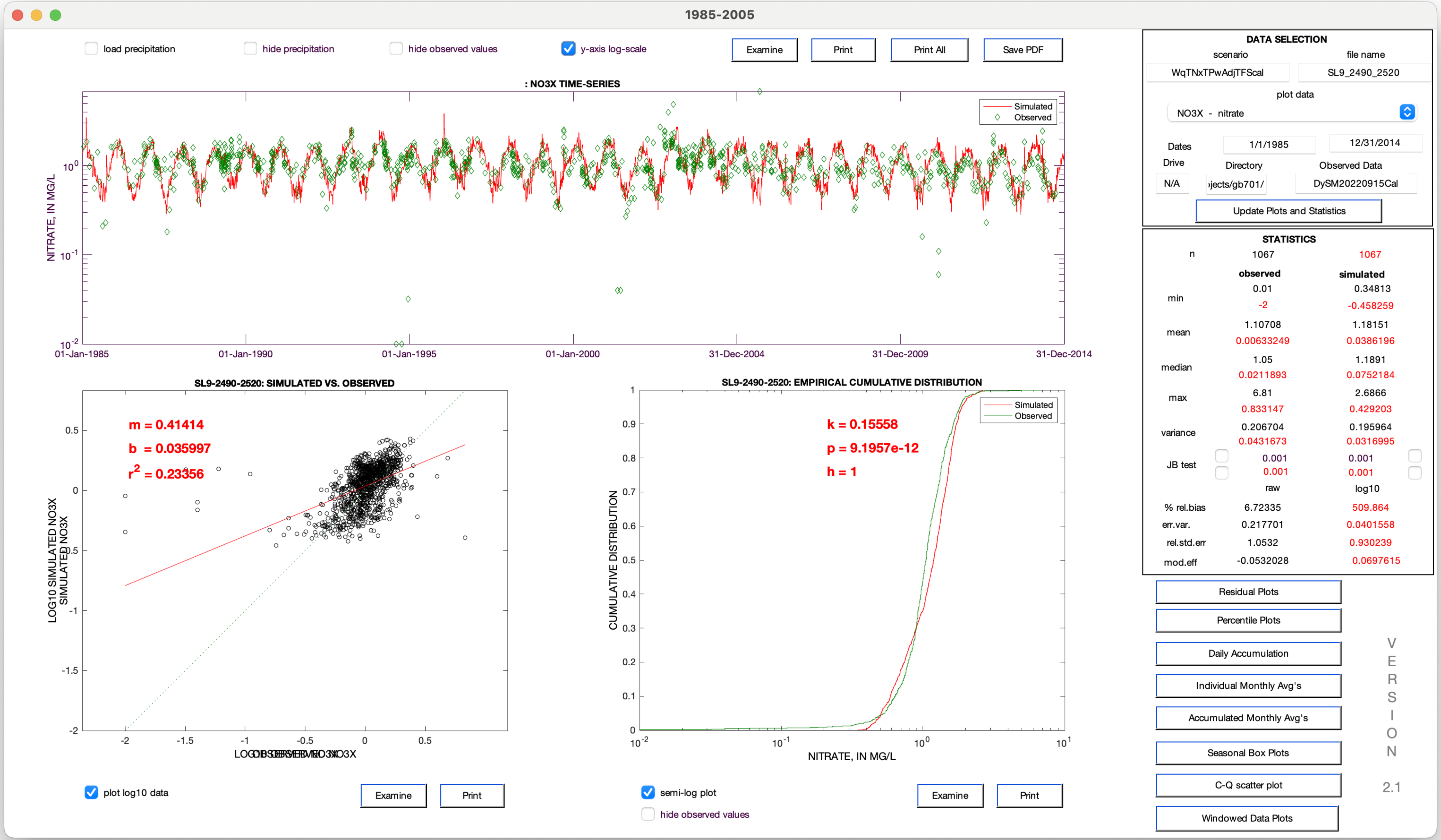
Nitrate



βs with calibration

Susquehanna at Marietta

Nitrate

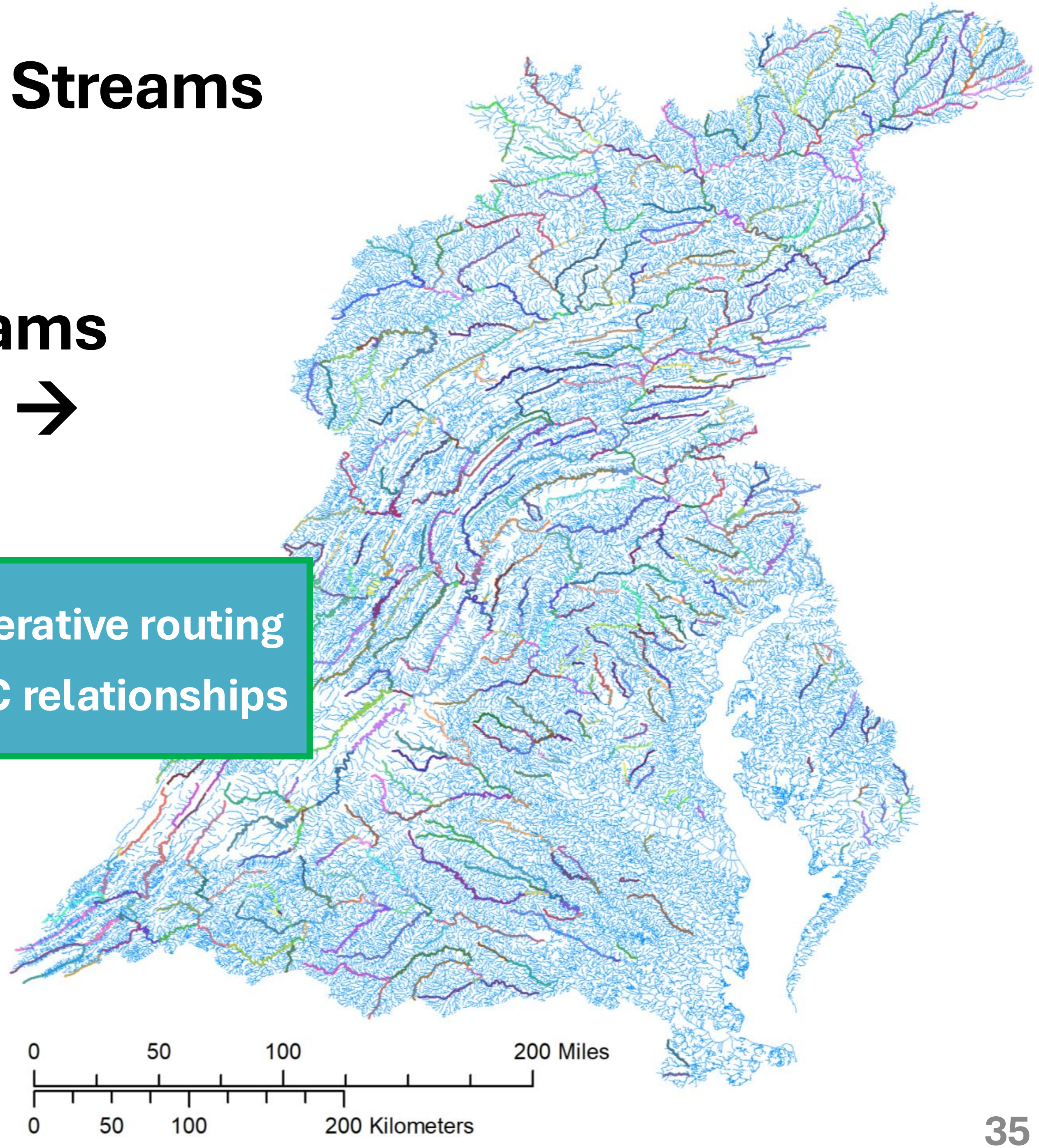


Scale and Simulation of Small Streams

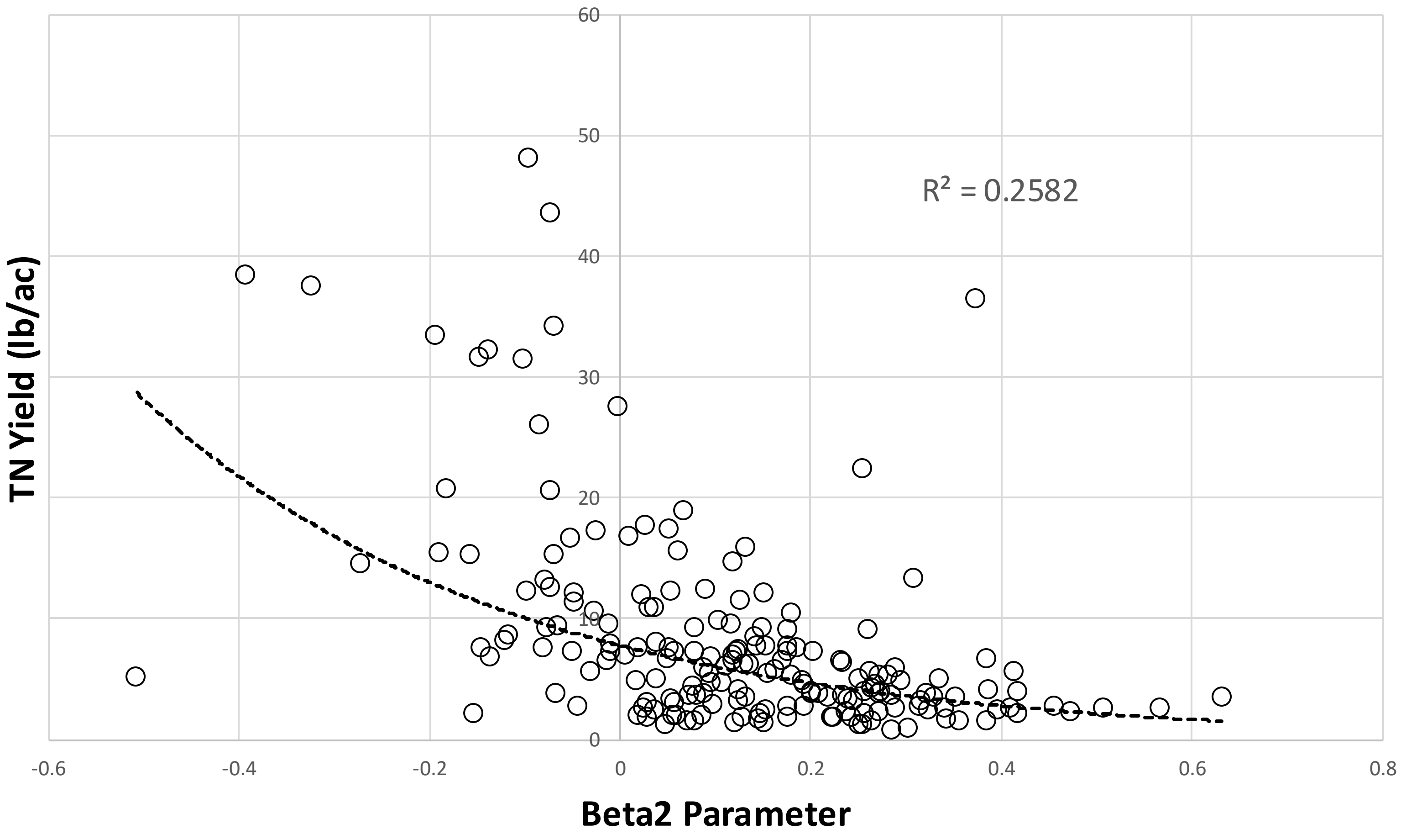
nested model
segmentation of streams
and river mainstems →

100K NHD STREAMS → **Hydrology: Non-iterative routing**
Water Quality: Q-C relationships

RIVER MAINSTEM → HSPF

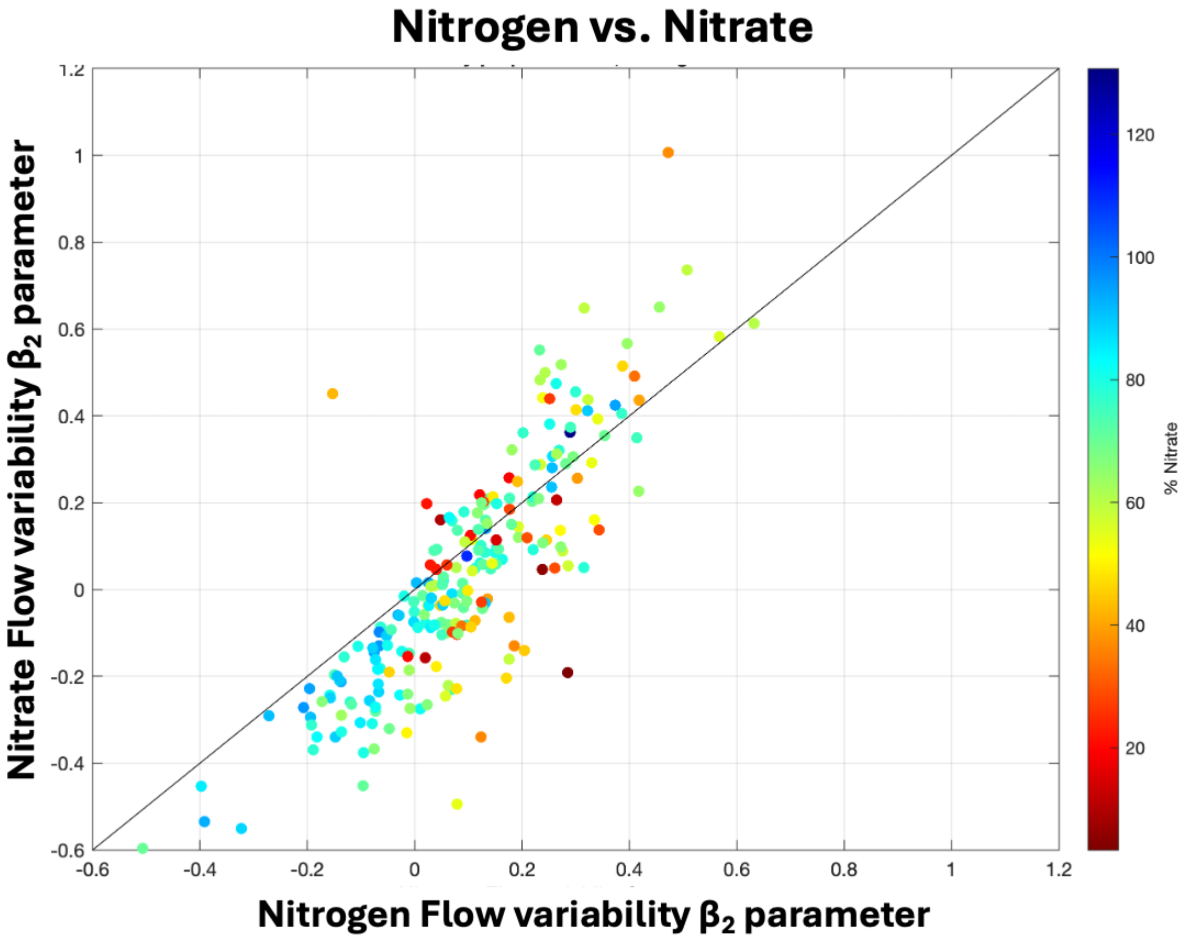


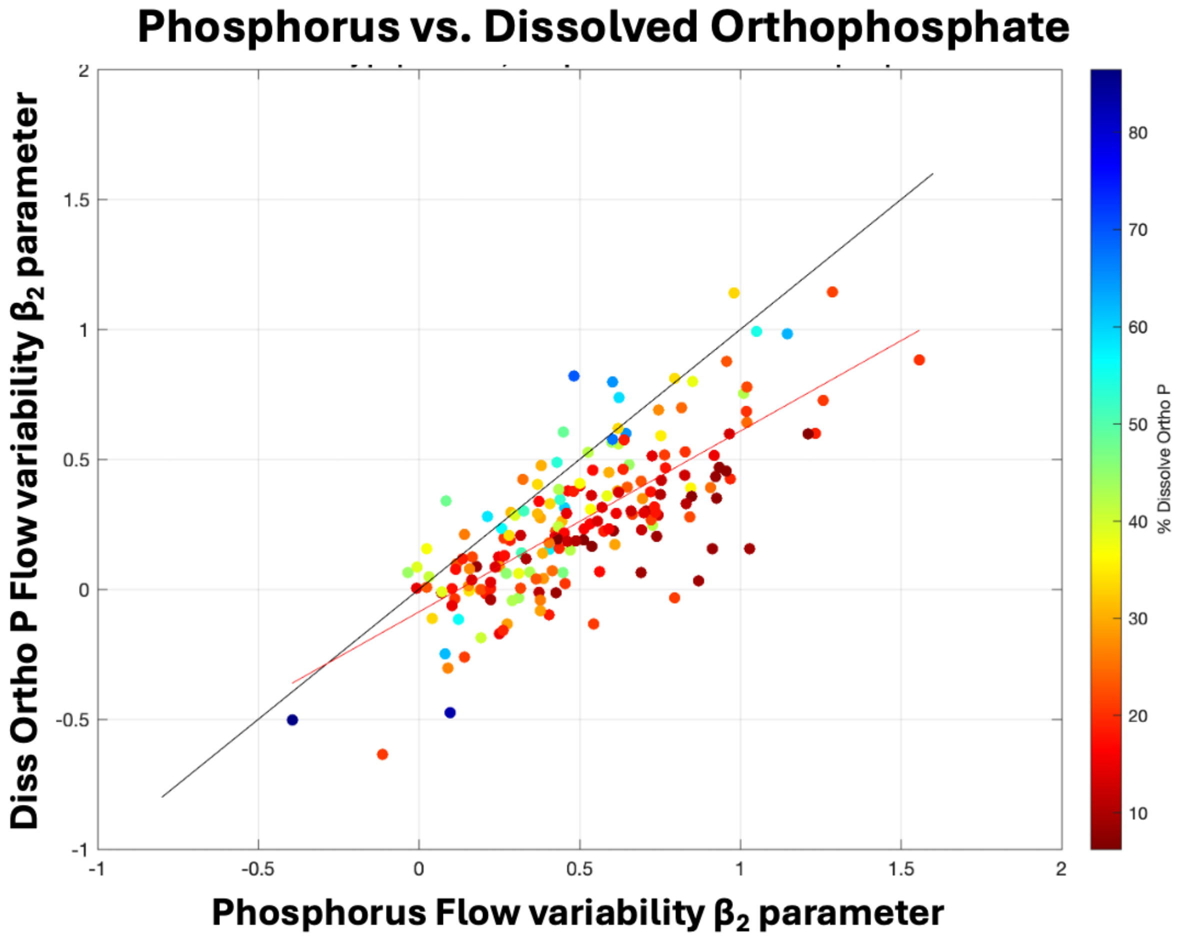
Explaining variability in β_2 parameter



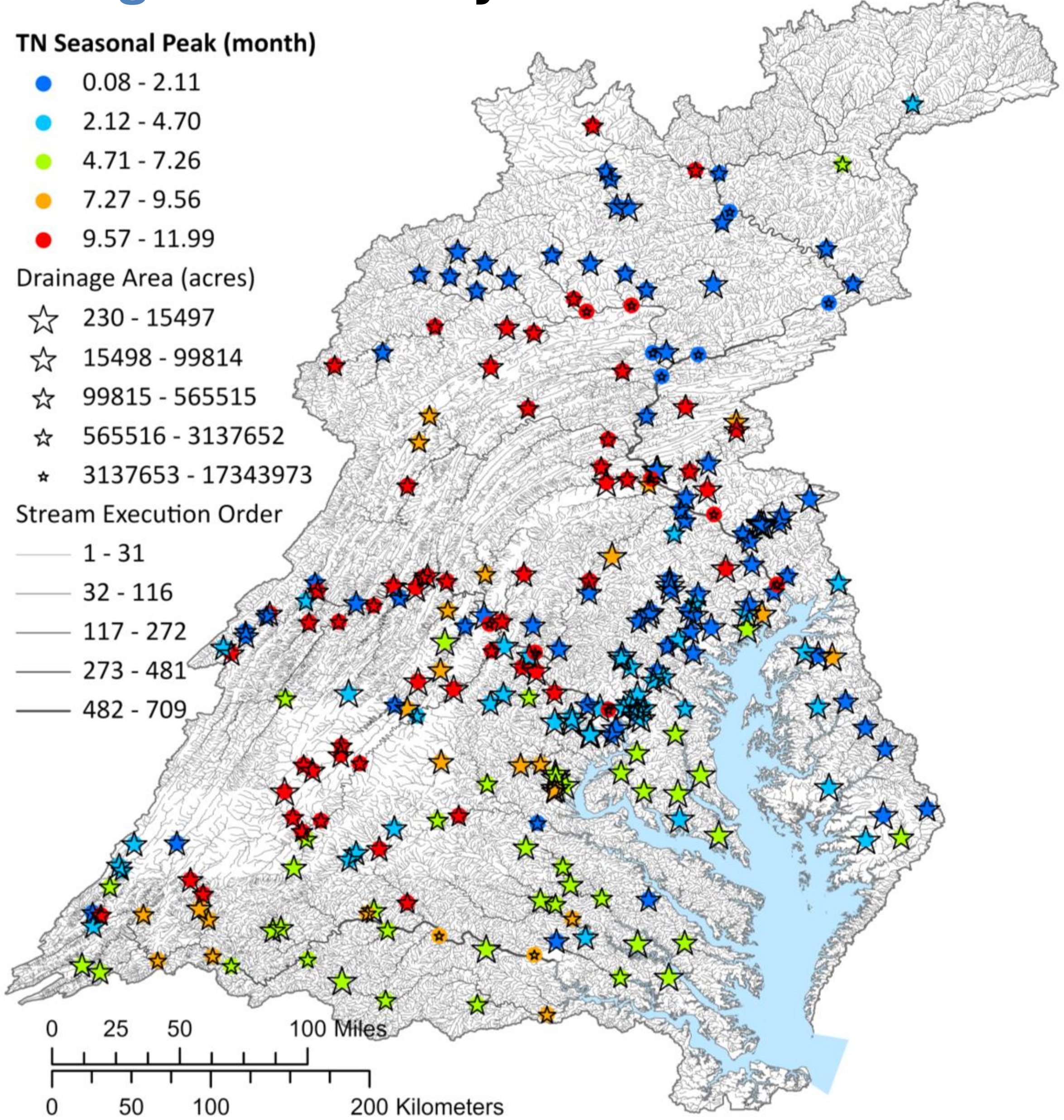
- ❖We have not fully investigated explaining the variability in β_2 parameters.
- ❖But spatial patterns are intriguing and so we think use of watershed properties and better analysis tools should be successful.

Flow variability, β_2 parameter

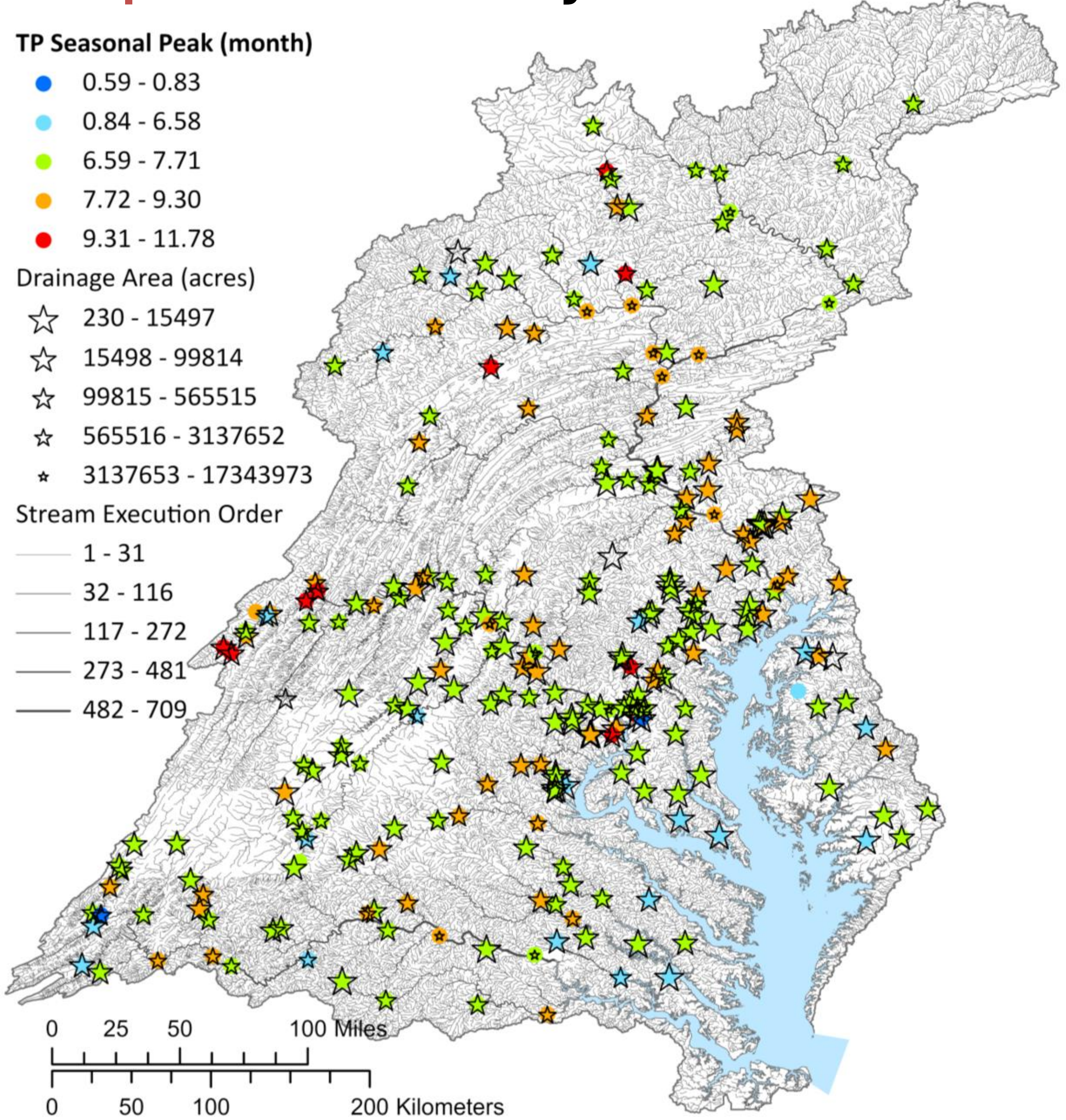




Nitrogen seasonality



Phosphorus seasonality



$$ln(c) = \beta_o + \beta_1 t + \beta_2 \ln(Q) + \boldsymbol{\beta_3} sin(2\pi t) + \boldsymbol{\beta_4} cos(2\pi t) + \varepsilon$$