04/01/2025

Phase 7 WSM Development – Linkage of the Dynamic Watershed Model (DWSM) and Main Bay Model (MBM)

Modeling Workgroup Quarterly Meeting – April 2025

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 (DWSM)

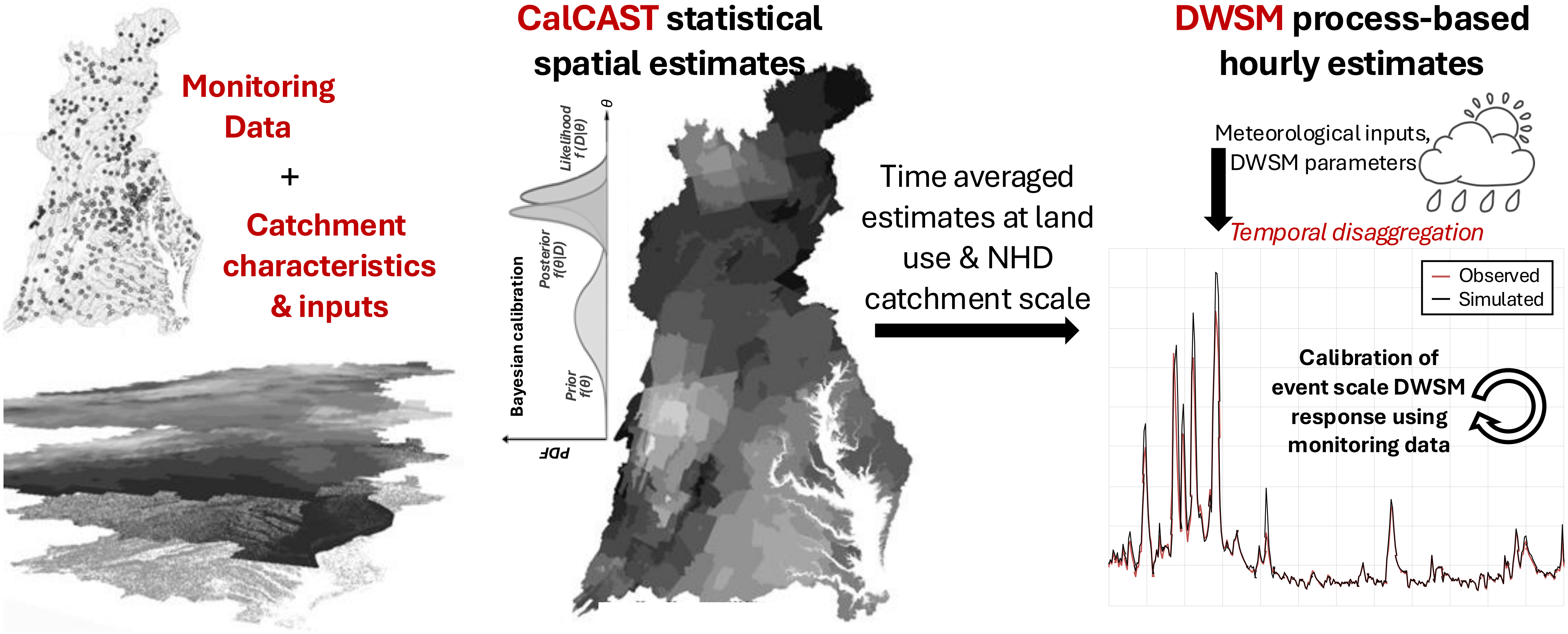
1. **Dynamic Watershed Model Overview**
2. **Review of prior model development progress**
3. **Linkage of the DWSM and Main Bay Model (MBM)**
    - New beta versions of the watershed loads and output in NetCDF
    - Revisiting hydrology calibration (NLDAS2 vs. PRISM precipitation)
    - Issue of nitrate simulation
    - New CMAQ data for improving Phase 7 CBP atmospheric N loads
    - Other general progress
4. **Summary and next steps**

Purpose

NHD Scale Dynamic Watershed Model (DWSM)

- 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 (DWSM)



- Data-driven CalCAST informs DWSM parameters and responses.
- NHD-scale DWSM 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 (DWSM) Development

- **Year 2022: NHD-scale model structure and prototypes for hydrology, sediment, and nutrients.**
- **Year 2023: Incremental refinements of model prototypes in terms of model segmentation, CalCAST→DWSM linkage, and simulation of the small streams.**
- **Year 2024: stream water quality routing based on β parameters; refinements of small stream flow and water temperature routing modules; mechanics of riverine water quality calibrations.**
- **Year 2025: development and testing of DWSM and MBM linkage through beta versions.**

CY2022
[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

CY 2023
[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

CY 2024
[1] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-CBPO-4.2.2024.pdf
[2] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Phase-7-WSM-Development-Modeling-WG-July-2024.pdf
[3] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/3_1000_20241008-BHATT-Phase-7-WSM-Development-Dynamic-Model-Development-2024Q3.pdf
[4] https://www.chesapeakebay.net/files/documents/1035-20250107-BHATT-Phase-7-WSM-Development-Dynamic-Model-Development-2024Q4.pdf

[3] December 2024

Updated CalCAST parameters (v20241031) + DWSM recalibration

Phase 7 RIM stations loads vs. WRTDS

(a) biases in 1985-2014 average loads as compared to WRTDS; (b) NSE of annual loads in parentheses;

Rivers	Flow	Nitrogen	Phosphorus	Sediment
Susquehanna Conowingo MD	+00.0% (+0.946)	-07.7% (+0.774)	+18.1% (+0.213)	+18.0% (+0.433)
Susquehanna Marietta PA	-01.2% (+0.938)	-08.3% (+0.496)	-14.0% (+0.132)	+02.6% (-0.115)
Potomac Washington, DC	+00.3% (+0.885)	-19.3% (+0.666)	-10.1% (+0.724)	-08.4% (-0.503)
James Cartersville, VA	+03.7% (+0.891)	-19.6% (+0.663)	-27.8% (+0.513)	-36.0% (+0.627)
Rappa. Fredericksburg, VA	-01.3% (+0.903)	-00.5% (+0.830)	-14.9% (-2.454)	-41.9% (-0.750)
Appomattox Matoaca, VA	00.0% (+0.903)	+12.9% (+0.416)	+24.5% (+0.216)	-32.7% (+0.534)
Pamunkey Hanover, VA	+03.6% (+0.815)	+04.3% (+0.750)	+13.6% (-0.388)	-44.2% (+0.229)
Mattaponi Beulahville, VA	+11.0% (+0.714)	+23.2% (+0.100)	+63.3% (-3.073)	+101.3% (-10.342)
Patuxent Bowie, MD	+03.8% (+0.857)	+01.3% (+0.494)	+01.3% (+0.693)	+28.7% (+0.501)
Choptank Greensboro, MD	-05.4% (+0.730)	+01.6% (+0.807)	+45.5% (+0.125)	-19.4% (+0.116)

(a) some differences can be attributed to WRTDS method and DWSM loads for the 1985-2014 averaging period

[5] January 2025

CalCAST (v20250114) + Septic + Sediment with HSPF + WQ recalibration

Phase 7 RIM stations loads vs. WRTDS

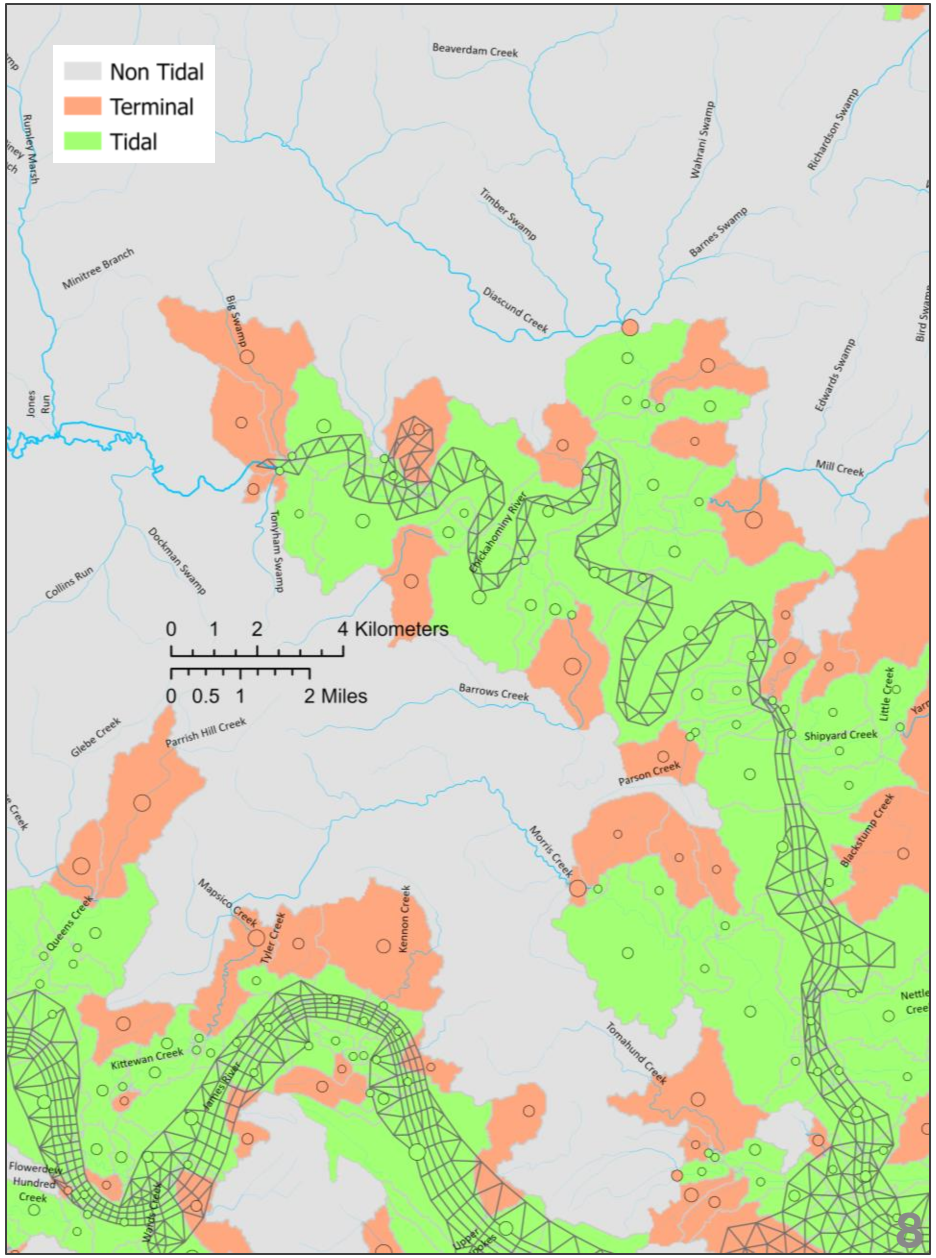
(a) biases in 1985-2014 average loads as compared to WRTDS; (b) NSE of annual loads in parentheses;

Rivers	Flow	Nitrogen	Phosphorus	Sediment
Susquehanna Conowingo MD	+00.0% (+0.946)	-08.2% (+0.784)	+20.2% (+0.495)	-17.5% (+0.499)
Susquehanna Marietta PA	-01.2% (+0.938)	-08.8% (+0.704)	-12.0% (+0.535)	+07.2% (-0.470)
Potomac Washington, DC	+00.3% (+0.885)	-19.0% (+0.683)	-05.6% (+0.627)	-02.3% (-0.085)
James Cartersville, VA	+03.7% (+0.891)	-18.3% (+0.726)	-17.5% (+0.770)	-24.0% (+0.662)
Rappa. Fredericksburg, VA	-01.3% (+0.903)	+00.4% (+0.822)	-03.7% (+0.458)	+02.8% (+0.104)
Appomattox Matoaca, VA	00.0% (+0.903)	+12.7% (+0.417)	+15.0% (+0.562)	+25.5% (-0.678)
Pamunkey Hanover, VA	+03.6% (+0.815)	+04.9% (+0.763)	+03.3% (+0.151)	+21.8% (-1.907)
Mattaponi Beulahville, VA	+11.0% (+0.714)	+21.2% (+0.212)	+13.7% (-0.333)	+48.9% (-3.989)
Patuxent Bowie, MD	+03.8% (+0.857)	+01.3% (+0.513)	-08.4% (+0.630)	+14.7% (+0.604)
Choptank Greensboro, MD	-05.4% (+0.730)	+01.8% (+0.807)	+11.9% (+0.561)	-17.9% (+0.124)

(a) some differences can be attributed to WRTDS method and DWSM loads for the 1985-2014 averaging period

NetCDF file has improved linkage of DWSM loads with MBM

- **We developed January 2025 and January Hybrid (P6 RIM + All Else Jan 2025 beta) beta versions.**
- **We reviewed and verified DWSM output data files, formats, units, and model variables.**
- **Spatial linkages [Zhengui Wang, VIMS] makes use of P7 NHD catchments geospatial layer with *terminal* and *tidal* attributes.**
- **Variable linkages [Richard Tian, CBPO; Zhengui Wang, VIMS] between DWSM and MBM are appropriately handled.**
- **One NetCDF file [Zhengui Wang, VIMS; Richard Tian, CBPO] replaced 234,306 [{2,858 + 10,159} x 18] DWSM output files.**



P7 loads are working well for small embayments in MBM

- Zhengui Wang (VIMS) and Wenfan Wu (VIMS) have developed tools for assessing and tracking watershed model outputs and estuarine model performance.

Table: Comparison of Phase 6 and Phase 7 watershed loads in small embayments. Data in parenthesis show RMSD of watershed model loads (Phase 6, Phase 7) as compared to that of immediately downstream tidal monitoring stations.

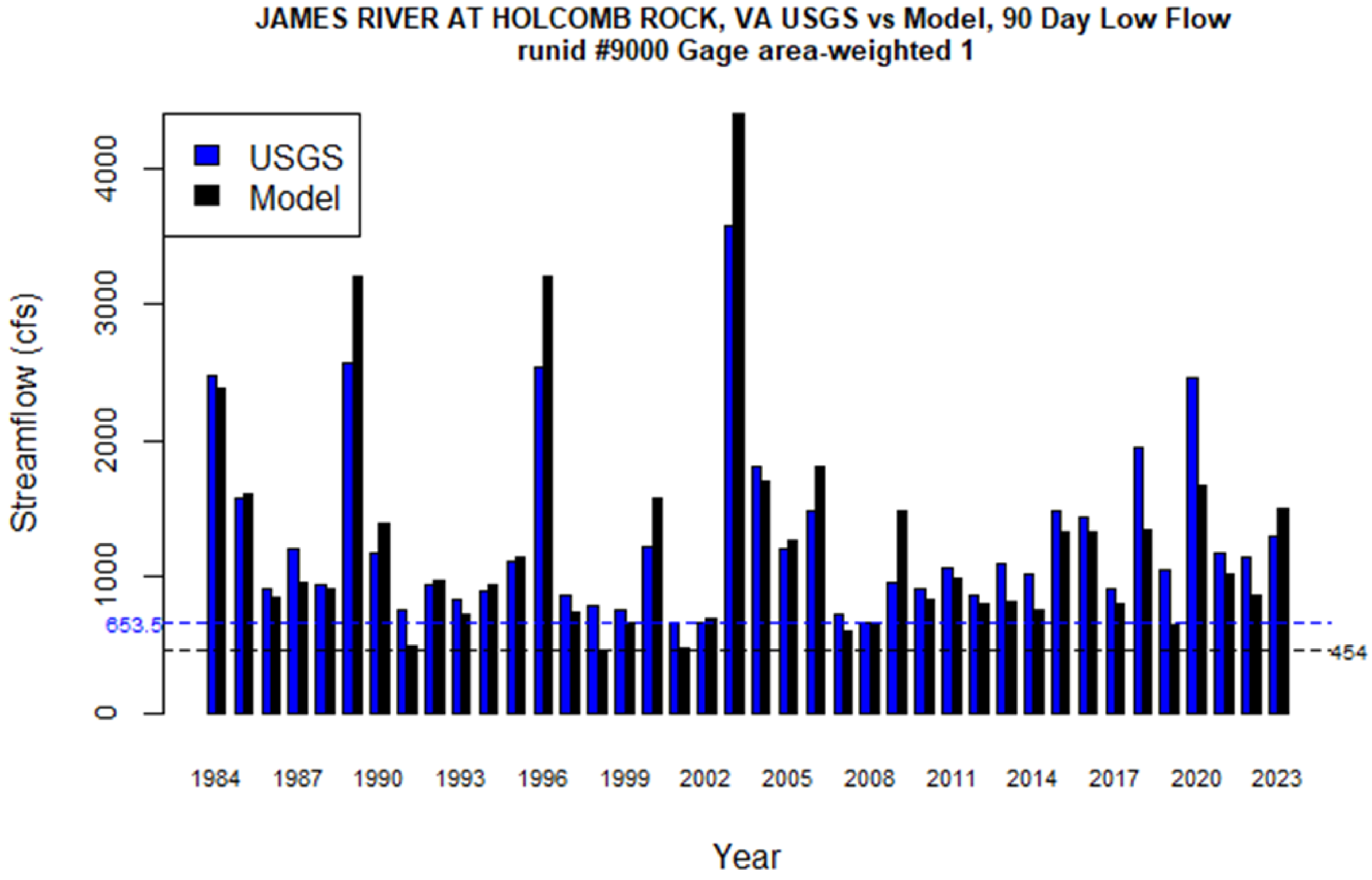
Embayments	River Impact	Salinity	Ammonia	Nitrate	Phosphate	Nitrogen	Phosphorus	Sediment
Sassafrass R.	99.5%	1.91	(0.1553, 0.1724)	(2.1799, 1.5663)	(0.0506, 0.0303)	(2.1749, 2.2918)	(0.1157, 0.0708)	(83.4010, 64.0950)
Bush R.	95.9%	0.84	(1.5825, 0.8445)	(2.4744, 2.0285)	(0.1267, 0.1176)	(3.0666, 2.1254)	(0.1737, 0.1249)	(59.0322, 53.9453)
Gunpowder R.	94.7%	1.63	(0.0774, 0.0722)	(1.0177, 0.4990)	(0.0122, 0.0164)	(0.8905, 0.4488)	(0.0471, 0.0442)	(41.6804, 37.5875)
South R.	69.1%	9.84	(0.1297, 0.1260)	(3.9673, 1.0413)	(0.0467, 0.0570)	(3.8474, 0.8997)	(0.0784, 0.0691)	(72.0014, 40.8683)
Piscataway R.	100.0%	0.00	(0.3453, 0.3234)	(5.3081, 3.5262)	(0.0381, 0.0407)	(5.3026, 3.7516)	(0.0702, 0.0805)	(50.1494, 36.6836)
Mattawoman C.	100.0%	0.02	(0.2073, 0.1016)	(4.8008, 1.8416)	(0.4483, 0.1060)	(5.5305, 1.7449)	(0.7417, 0.1505)	(57.9953, 37.4156)
Corrotoman R.	56.6%	14.53	(0.1101, 0.0573)	(1.8100, 0.7028)	(0.0223, 0.0406)	(1.8435, 0.5316)	(0.0785, 0.0431)	(61.3329, 12.5883)
Chickahominy R.	99.7%	1.18	(0.9466, 0.0622)	(5.4596, 0.1991)	(0.0683, 0.0370)	(7.2374, 0.3392)	(0.1628, 0.0585)	(59.5836, 49.2633)
Nanticoke R.	99.8%	0.19	(0.1803, 0.1174)	(2.9407, 1.4765)	(0.0436, 0.0748)	(2.8671, 1.2300)	(0.0962, 0.0807)	(35.9075, 35.1593)
Manokin R.	49.0%	13.87	(1.1536, 0.1188)	(3.7258, 1.3950)	(0.0762, 0.1538)	(4.8577, 1.6415)	(0.1603, 0.1767)	(43.1494, 30.3107)
Big Annemessix R.	47.8%	15.41	(10.0068, 0.2549)	(17.8570, 1.7639)	(0.4463, 0.1978)	(25.9882, 2.5115)	(0.8129, 0.2395)	(85.0987, 19.1356)
Patapsco R.	80.8%	10.42	(3.5302, 3.2289)	(2.9920, 2.4831)	(0.2444, 0.2266)	(6.6460, 5.9269)	(0.3410, 0.3307)	(55.0892, 39.3605)
Anacostia R.	100.0%	0.17	(0.2177, 0.2341)	(2.7501, 0.3297)	(0.0824, 0.0522)	(1.7004, 0.8990)	(0.0571, 0.0756)	(95.3317, 80.2096)
Elizabeth S.	46.9%	19.08	(1.8986, 0.4678)	(4.3389, 1.0248)	(0.8990, 0.2319)	(7.6235, 1.3427)	(1.2829, 0.3256)	(14.6792, 13.5410)
Chester R.	99.3%	0.49	(0.1221, 0.1062)	(1.0766, 1.2225)	(0.0301, 0.0733)	(0.9874, 1.1437)	(0.1563, 0.1110)	(87.0498, 91.7857)
Pocomoke R.	100.0%	0.20	(0.2716, 0.0722)	(0.7283, 0.6284)	(0.0953, 0.0869)	(1.1926, 0.6074)	(0.1445, 0.1108)	(30.9019, 23.7107)

PRISM resulted in better hydrology performance than NLDAS…

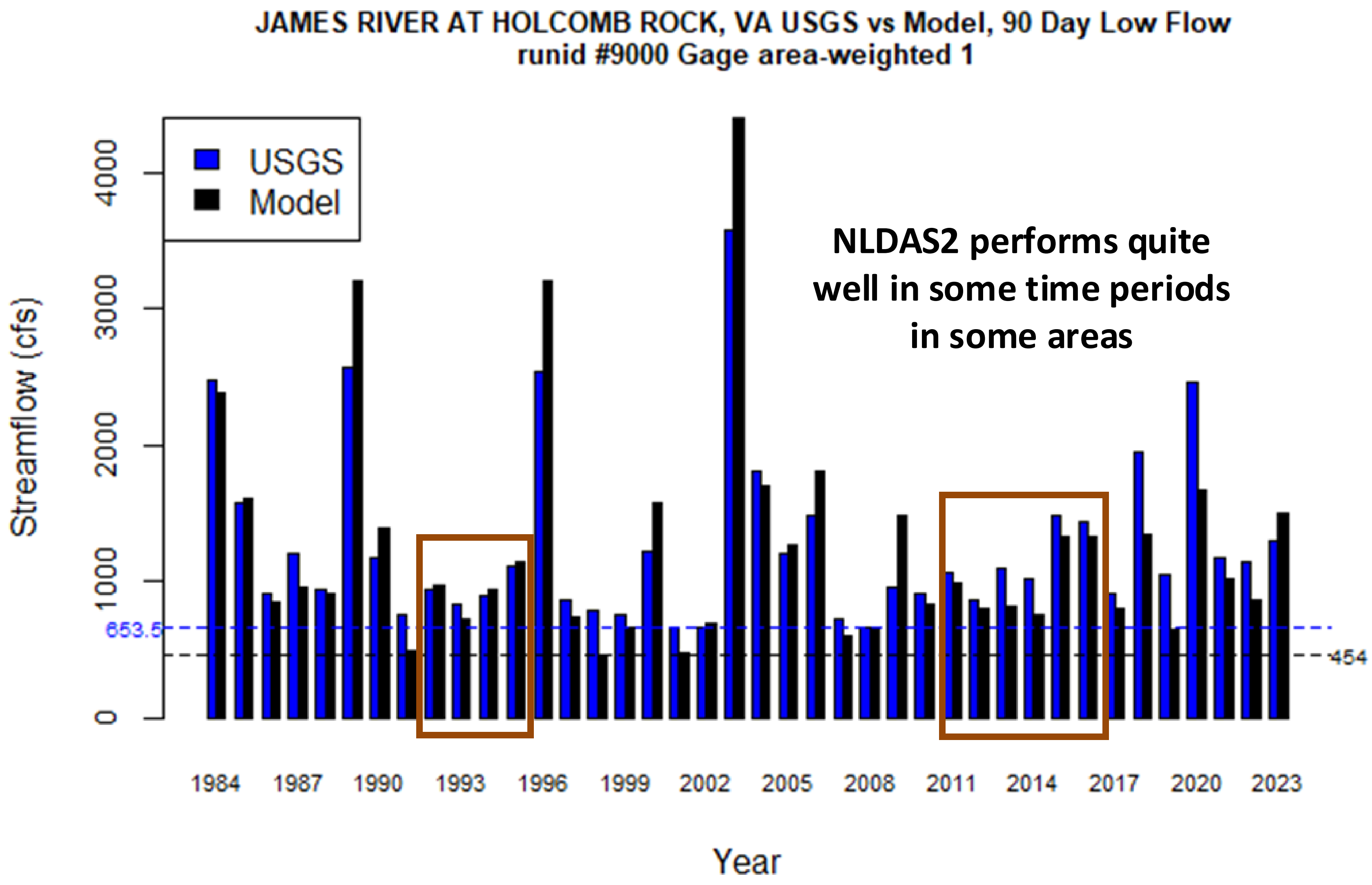
Revisiting hydrology calibration (NLDAS2 vs. PRISM)

- **There are several sources of reanalysis precipitation data.**
- **NLDAS2 (North American Land Data Assimilation System) has been our default source of precipitation data.**
  - **Hourly dataset**
  - **Includes other surface meteorological data**
  - **Near real-time availability**
- **PRISM (Parameter-elevation Regressions on Independent Slopes Model)**
  - **Widely used daily precipitation data**
- **Robert Burgholzer (VADEQ) and Connor Brogan (VADEQ) have been carefully looking into the suitability of precipitation data for regional hydrology modeling.**

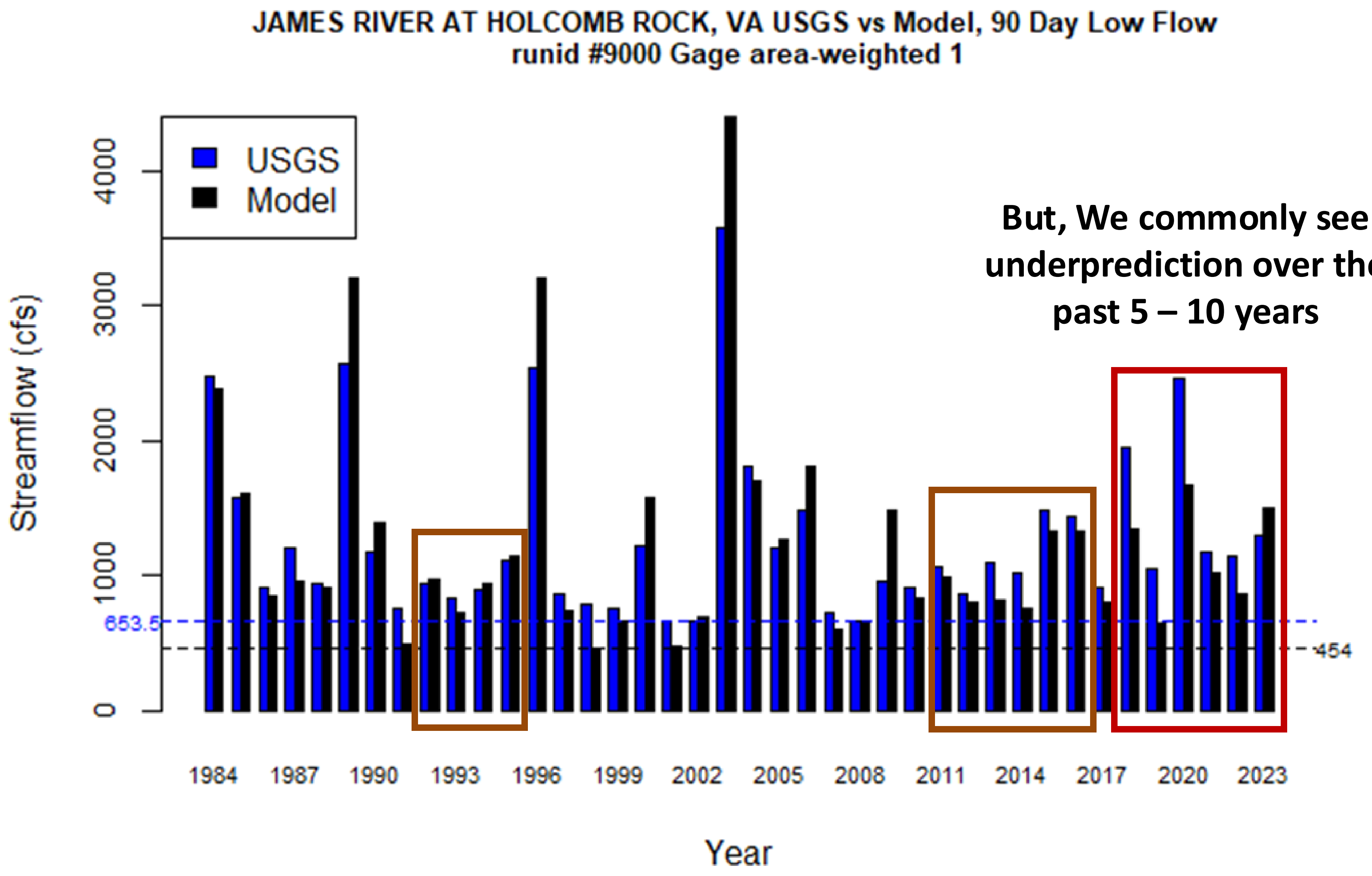
NLDAS2 Performance



NLDAS2 Performance

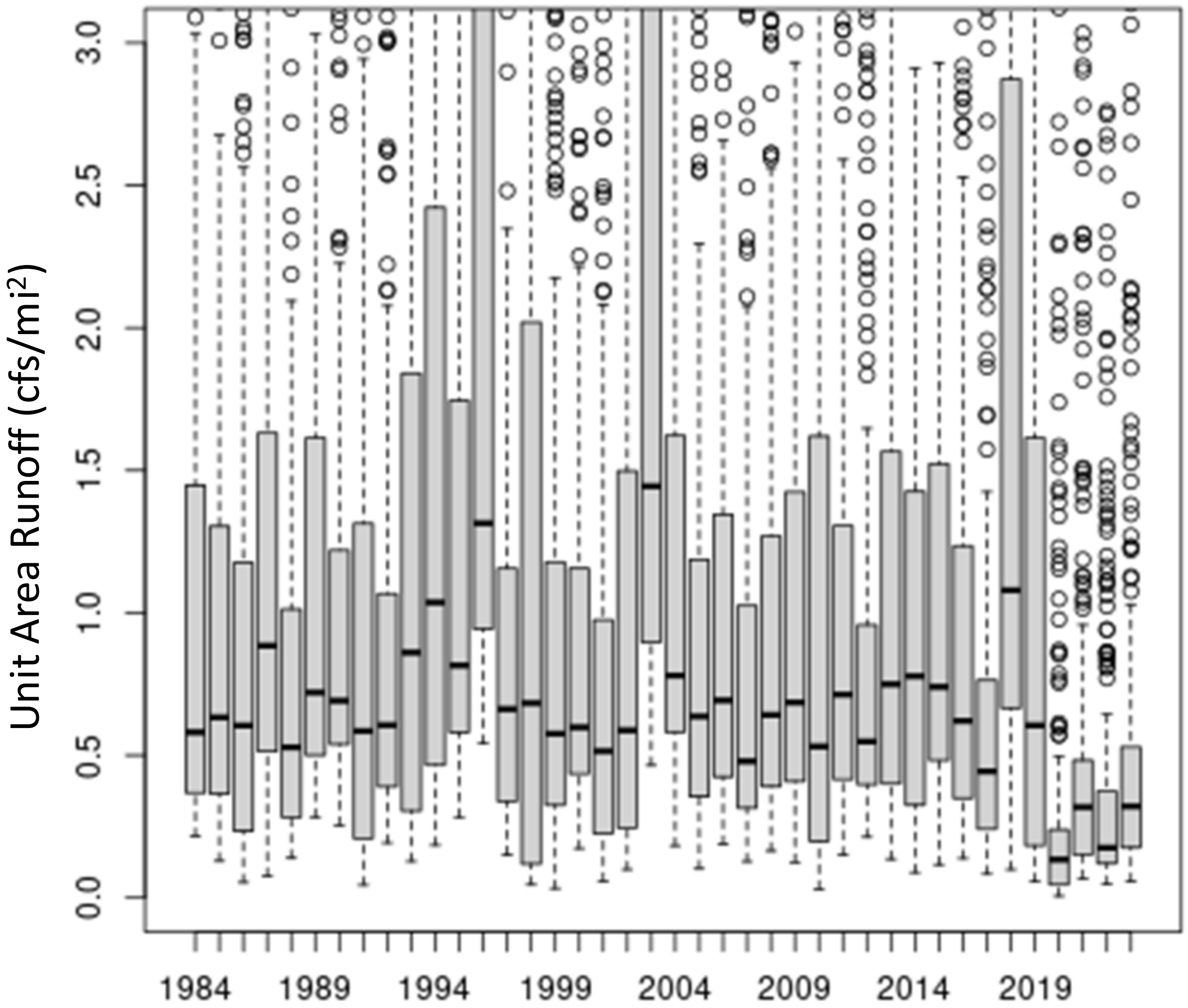


NLDAS2 Performance

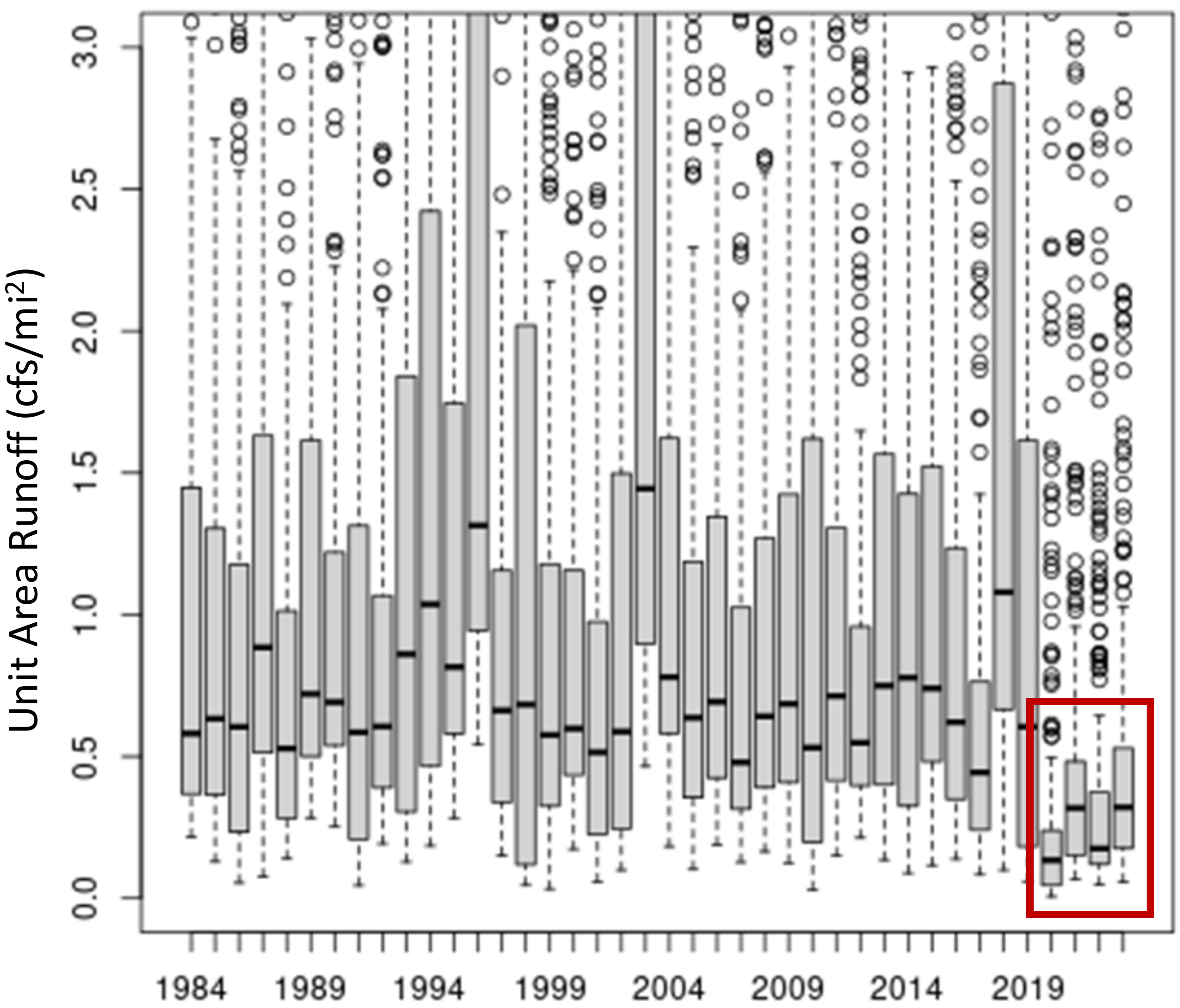


But, We commonly see underprediction over the past 5 – 10 years

NLDAS2 Performance – Potomac River



NLDAS2 Performance – Potomac River



Rainfall is very low over the past several years in NLDAS2 across the state. Is that accurate?

Available Precip Data for Model Domain

PRISM – Oregon State

- Model that aggregates data from a wide range of monitoring network with extensive QC
- Daily, 1895 – Present (Less accurate prior to 1981)
- 4 x 4km

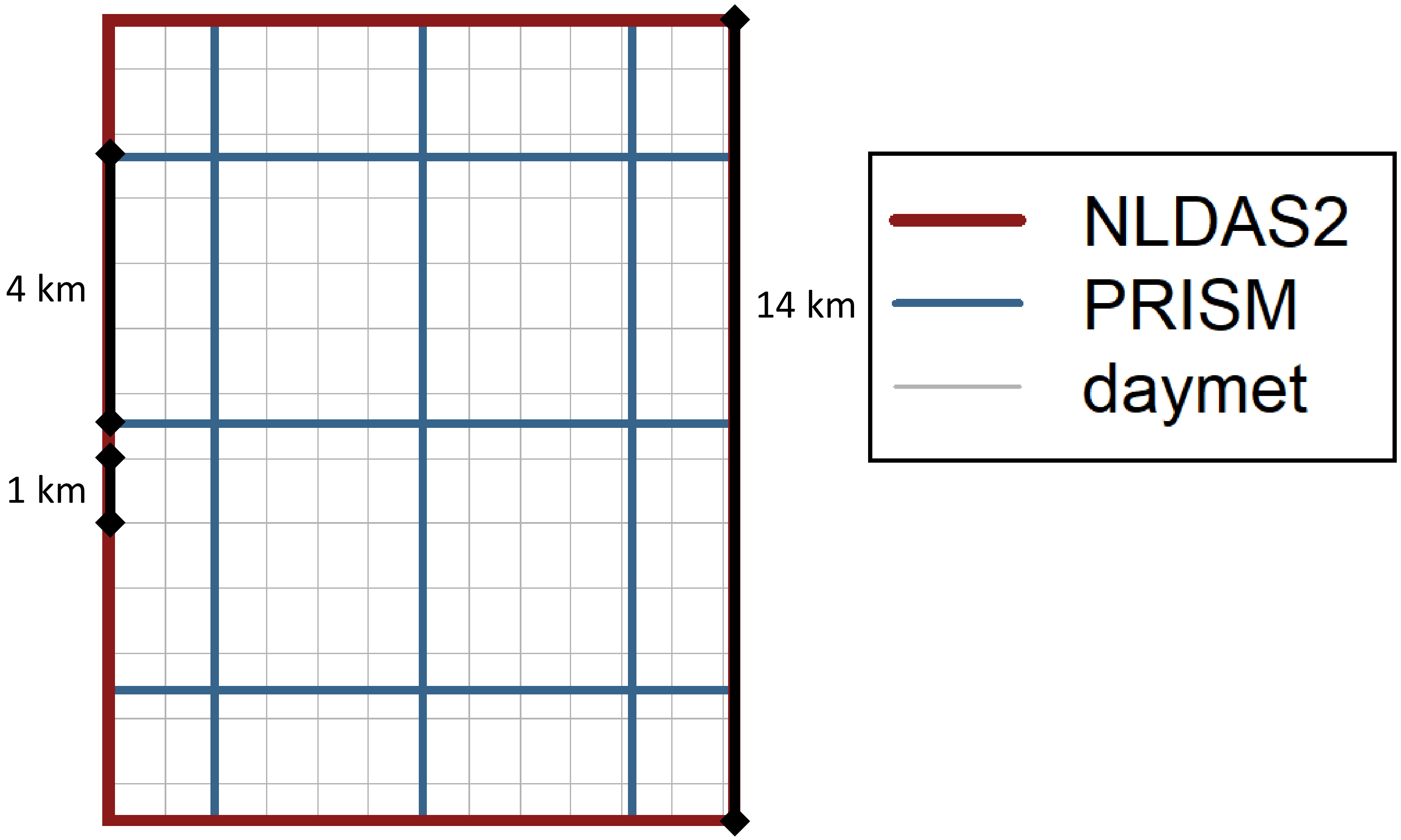
daymet – NASA ORNL

- Modeled via Interpolations and extrapolations from meteorological observations
- Daily, 1980 – 2023
- 1 x 1km
- December 31st missing on leap years

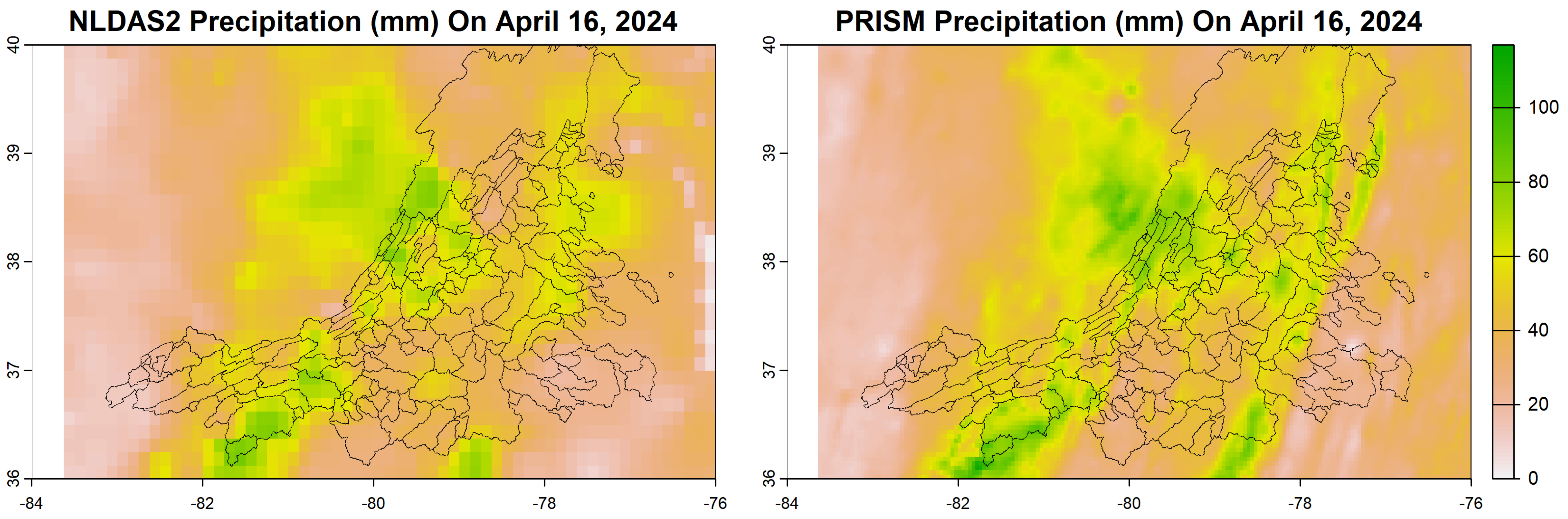
NLDAS2 – NASA

- Hourly, 1979 – Present
- ~14 x 14 km

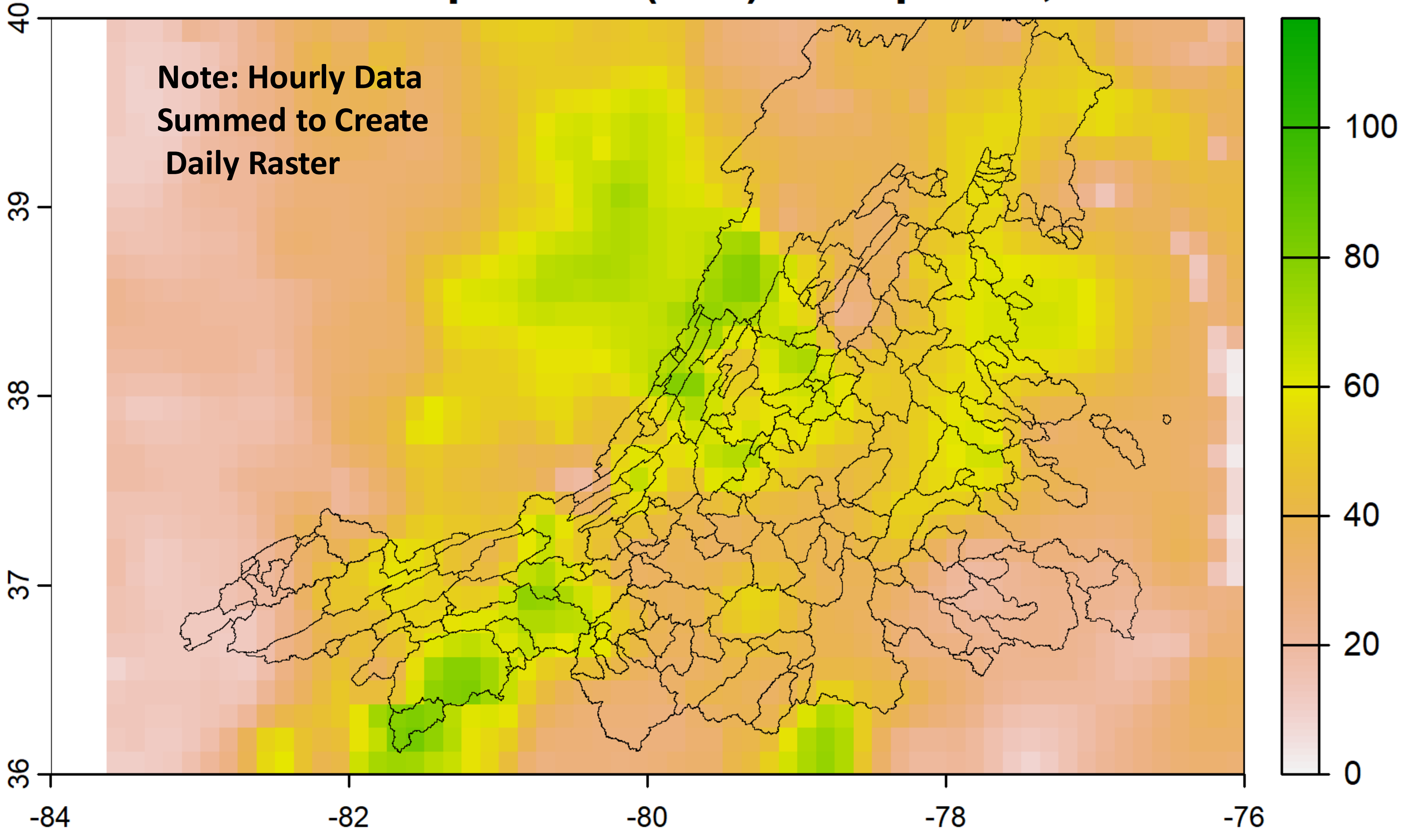
Precip. Data Source Resolution



met → geo → amalgamate → wdm → OM

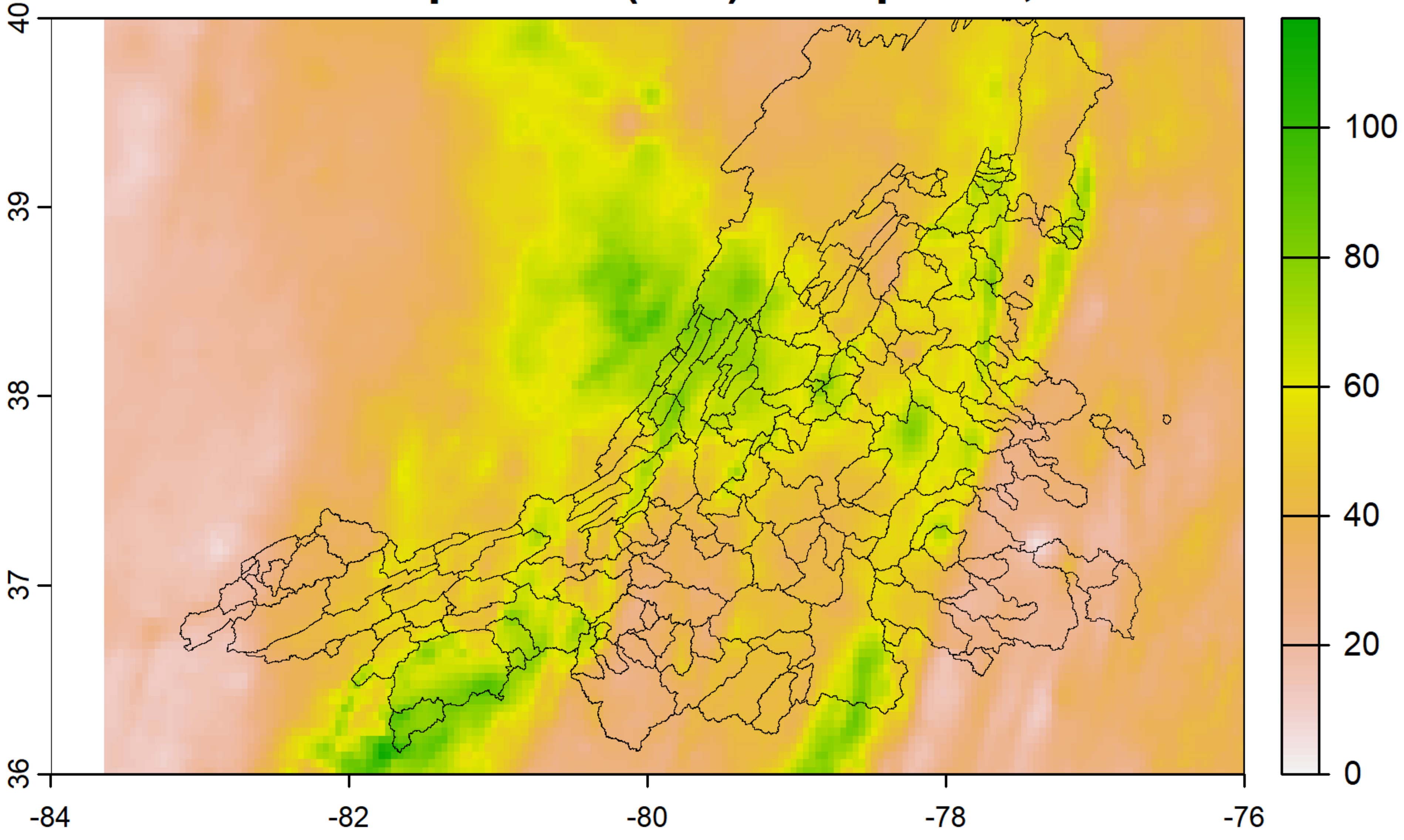

NLDAS2 Precipitation (mm) On April 16, 2024
PRISM Precipitation (mm) On April 16, 2024
40
39
38
37
36
-84
-82
-80
-78
-76
100
80
60
40
20
0

NLDAS2 Precipitation (mm) On April 16, 2024



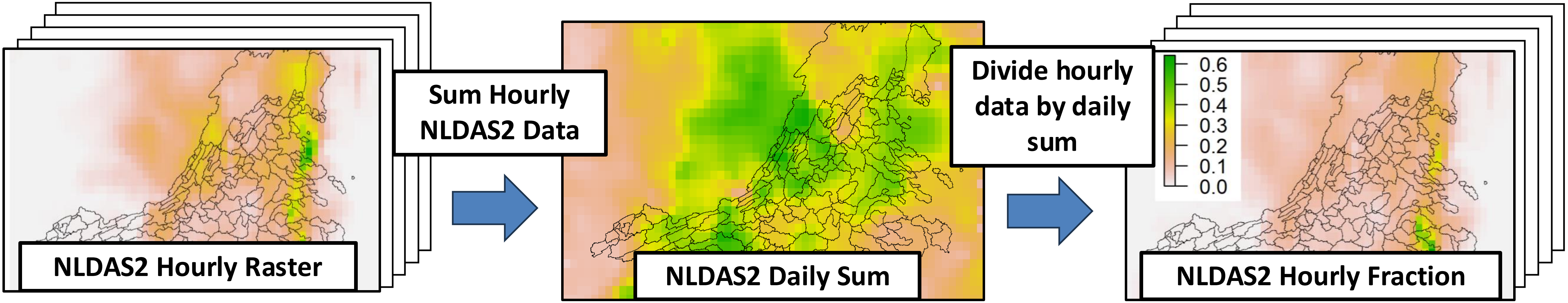
met → geo → amalgamate → wdm → OM

PRISM Precipitation (mm) On April 16, 2024

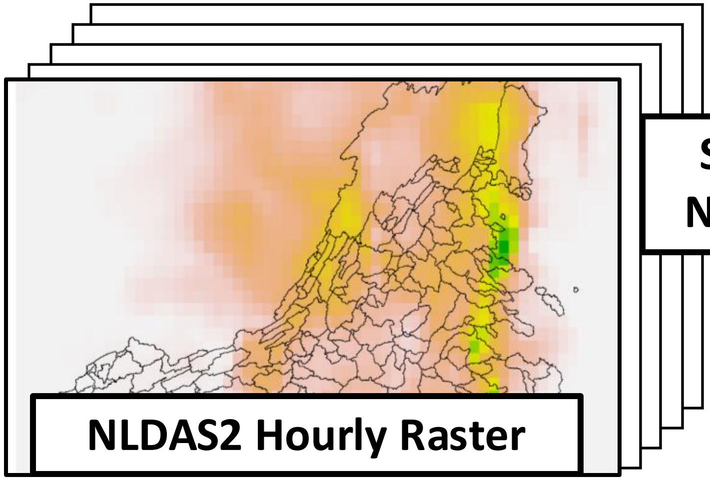


met → geo → amalgamate → wdm → OM

Temporal Disaggregation

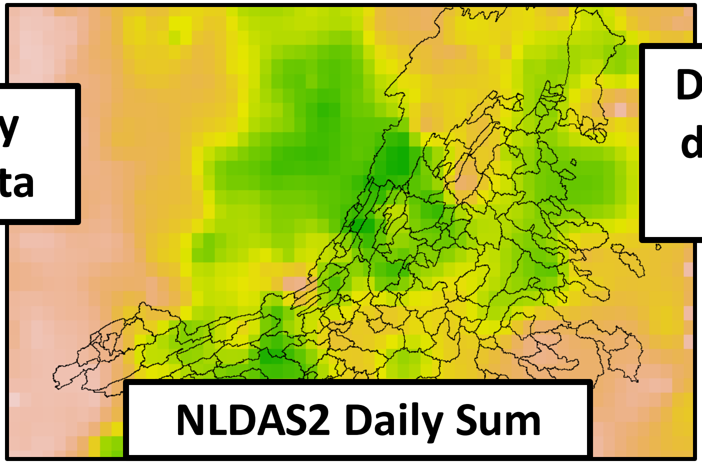


Temporal Disaggregation



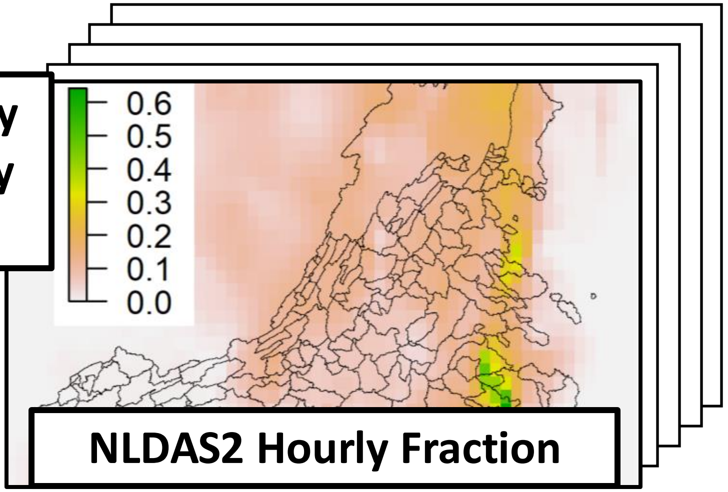
NLDAS2 Hourly Raster

Sum Hourly NLDAS2 Data

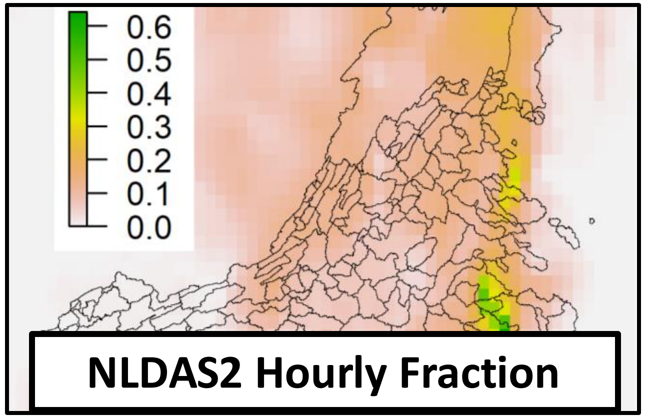


NLDAS2 Daily Sum

Divide hourly data by daily sum

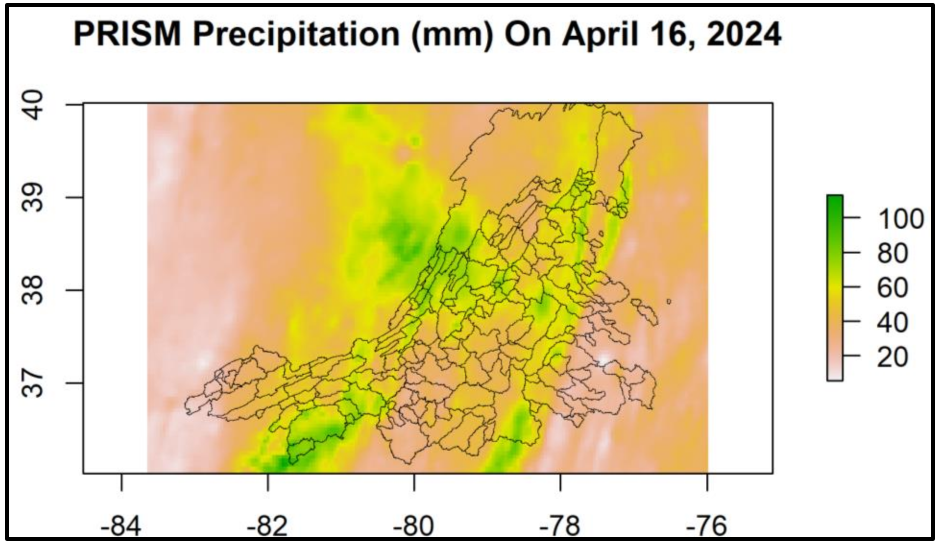


NLDAS2 Hourly Fraction



NLDAS2 Hourly Fraction

Multiply Hourly Fraction by daymet/PRISM Daily Data

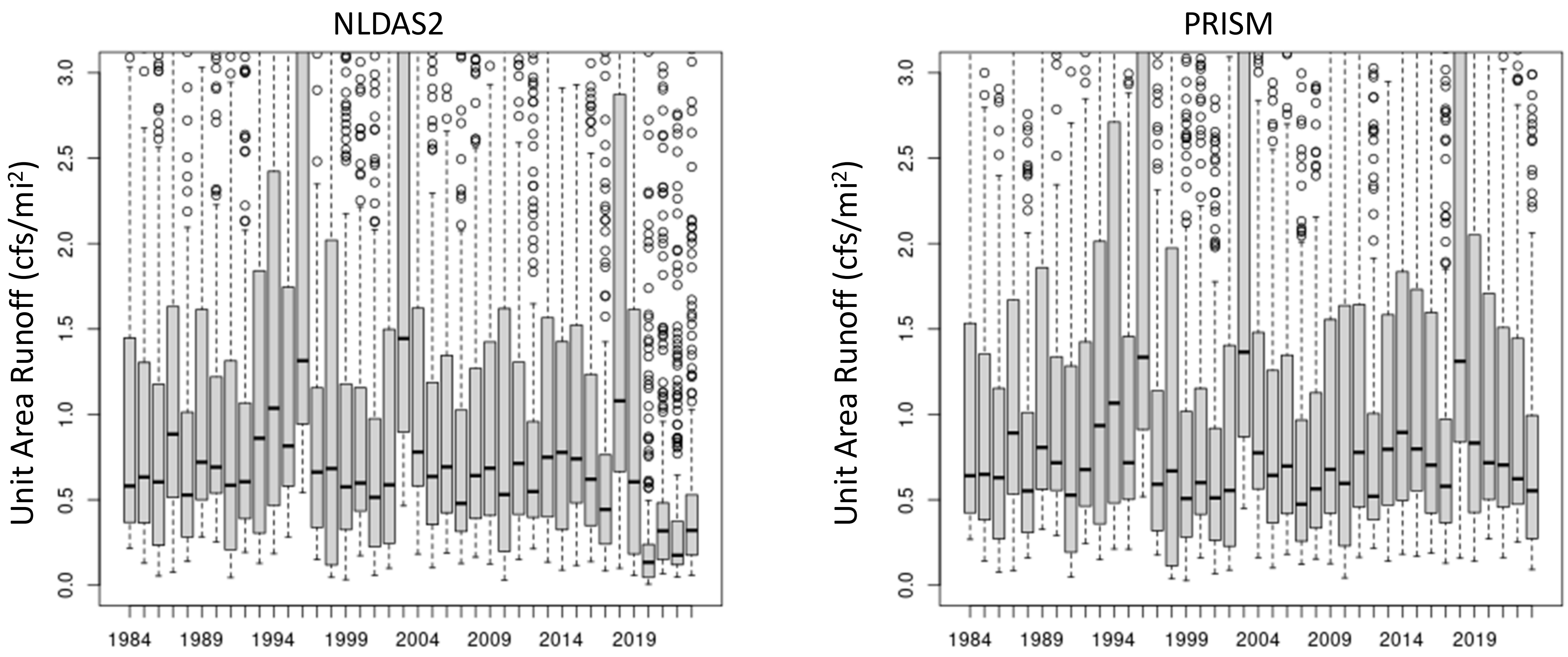


Hourly PRISM or daymet Data!

*If no NLDAS2 rainfall occurred, use 1/24 as the fractional multiplier

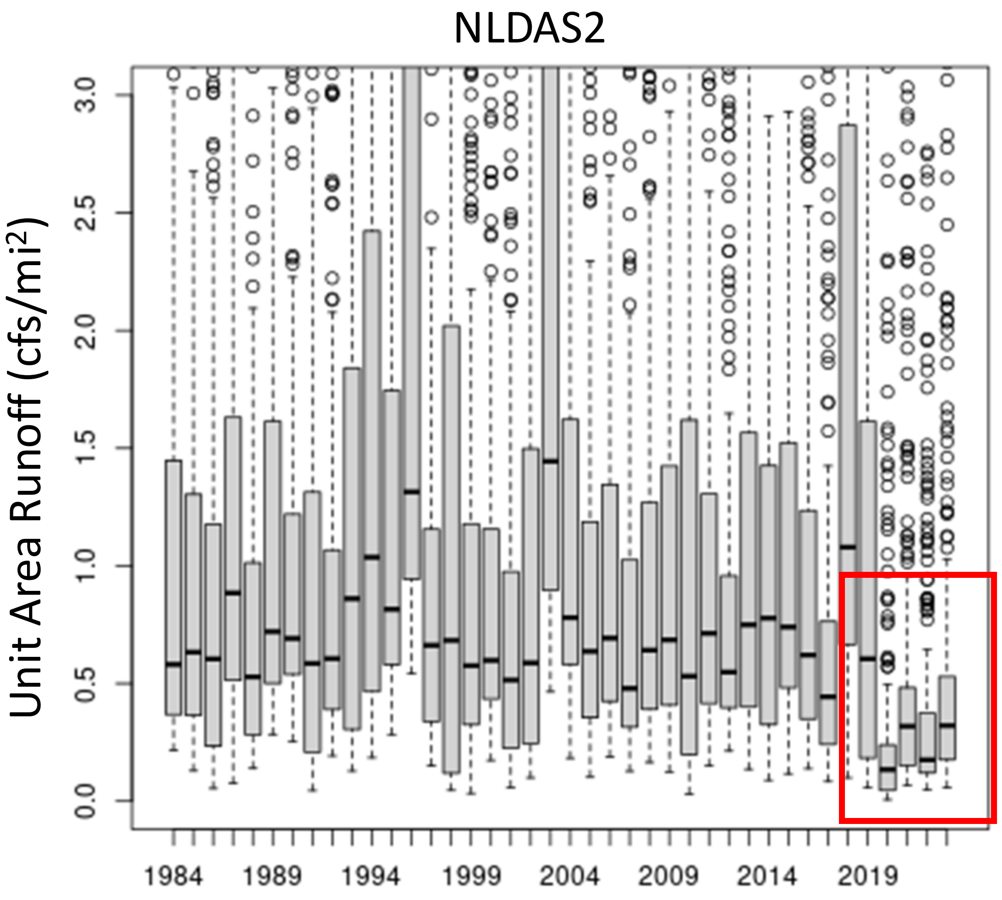
met → geo → amalgamate → wdm → OM

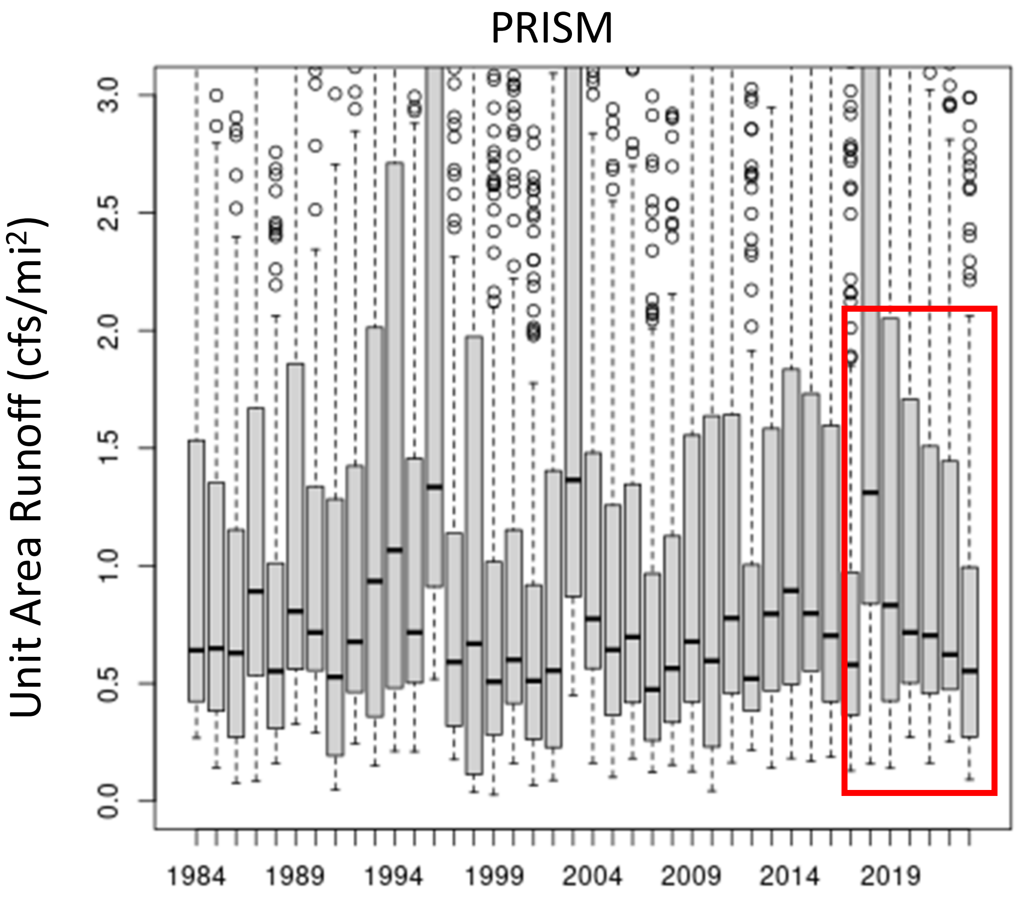
P6 Land Segment Runoff



met → geo → amalgamate → wdm → **OM**

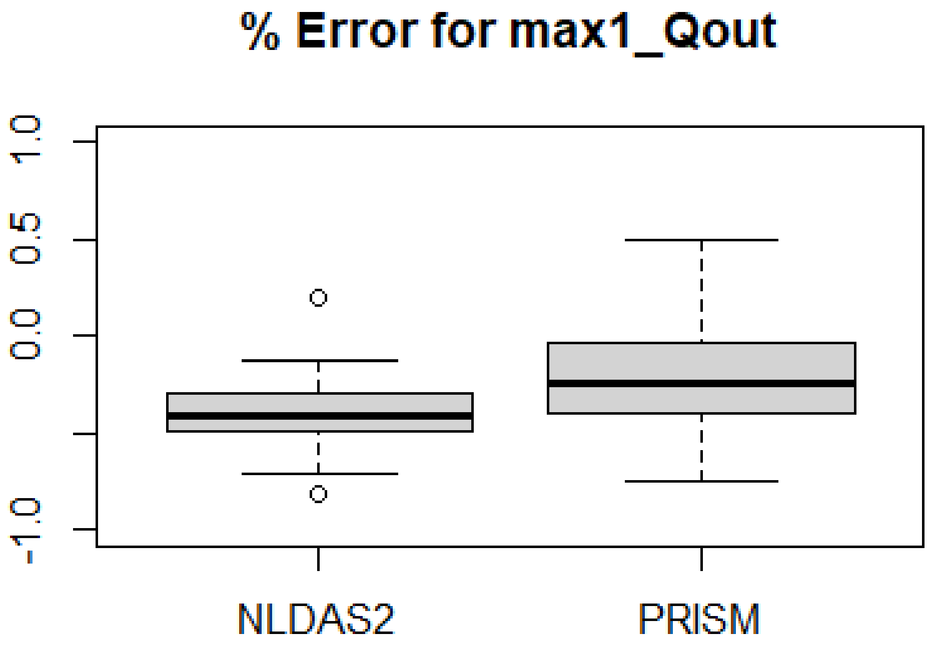
P6 Land Segment Runoff

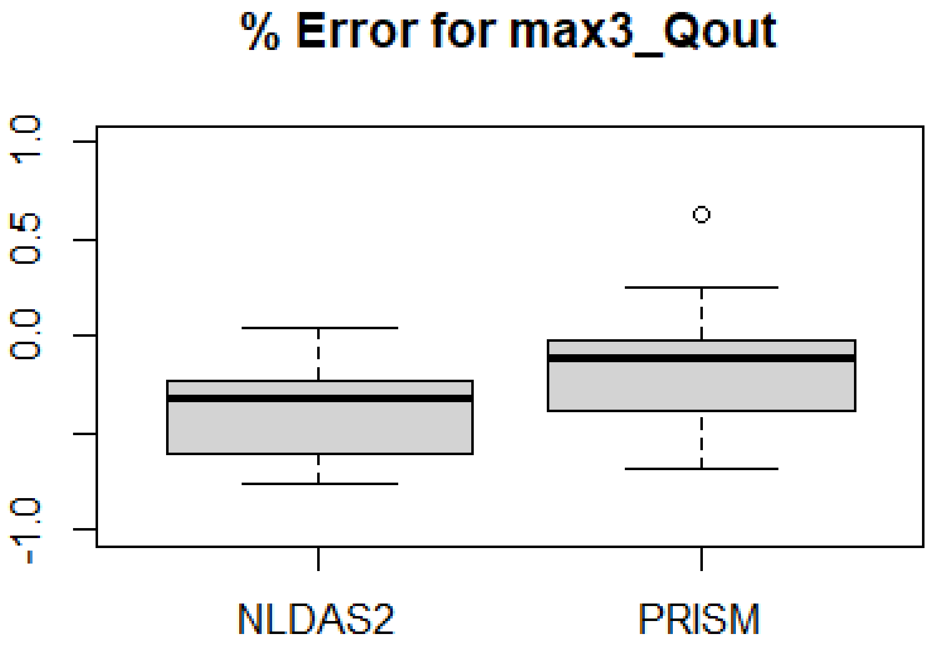




met → geo → amalgamate → wdm → **OM**

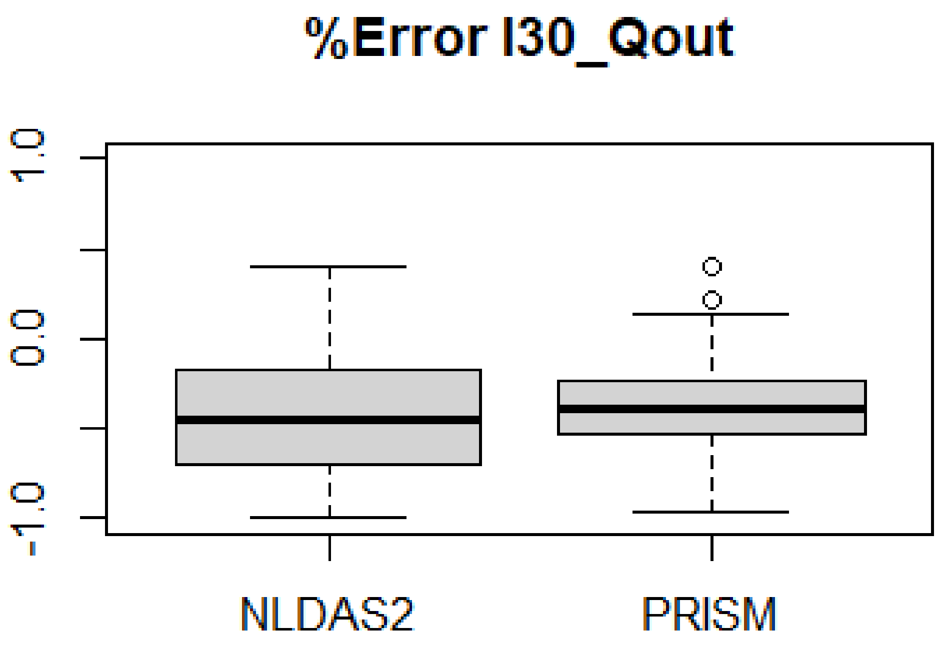
P6 PRISM vs NLDAS2 Model Results

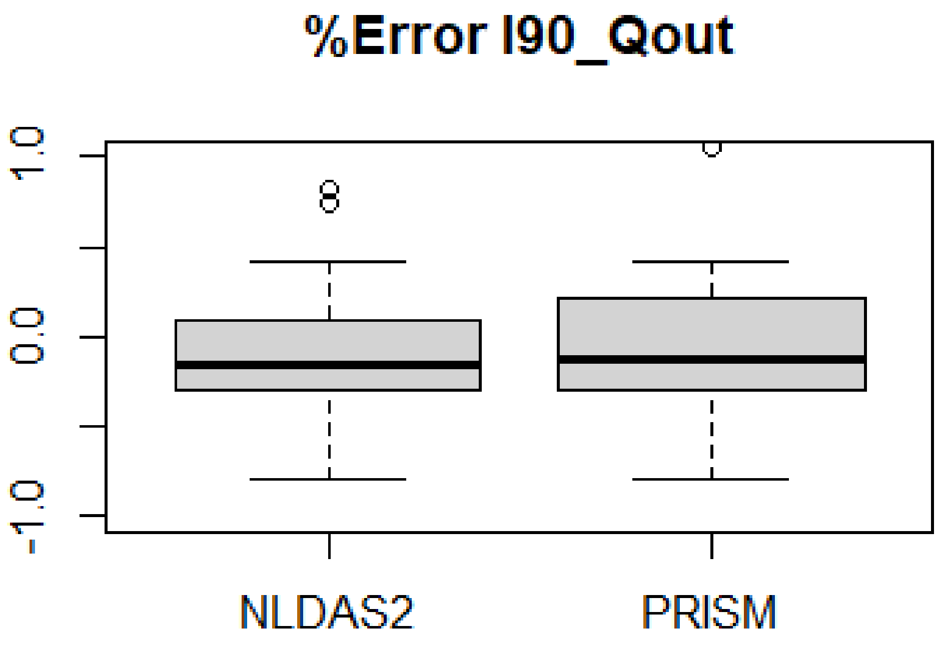




*Note: PRISM model was not calibrated

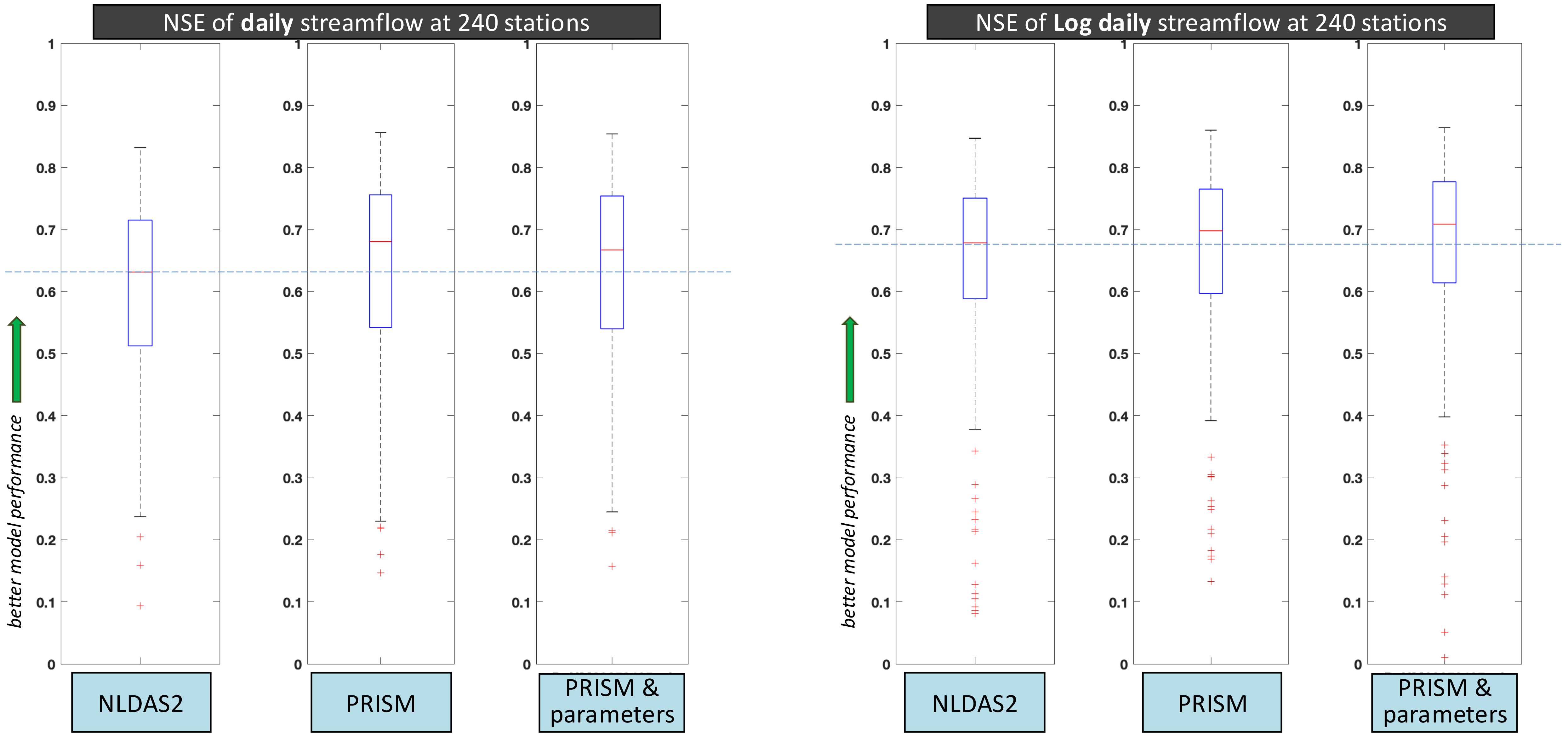
P6 PRISM vs NLDAS2 Model Results (Low Flow)





*Note: PRISM model was not calibrated

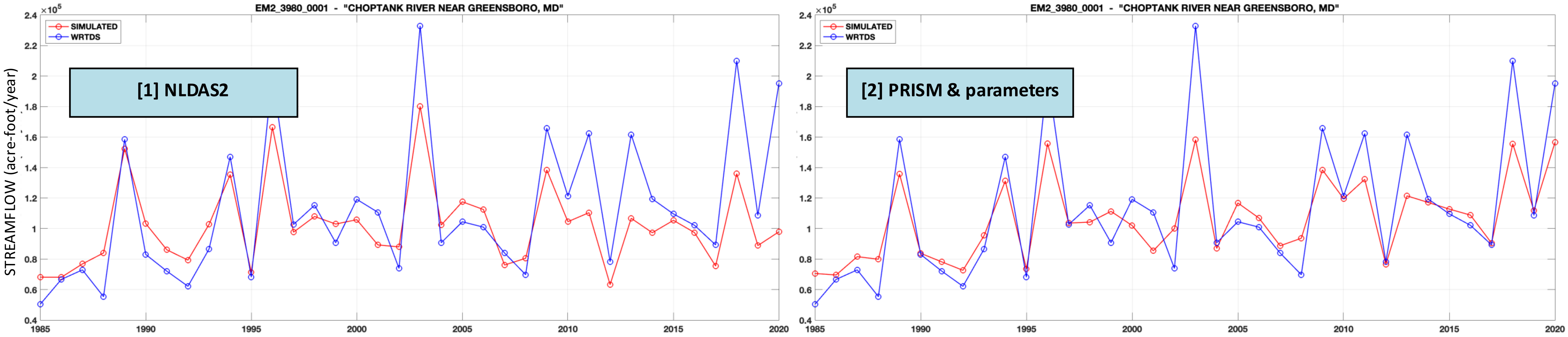
PRISM resulted in better model performance than NLDAS



PRISM improves annual flow

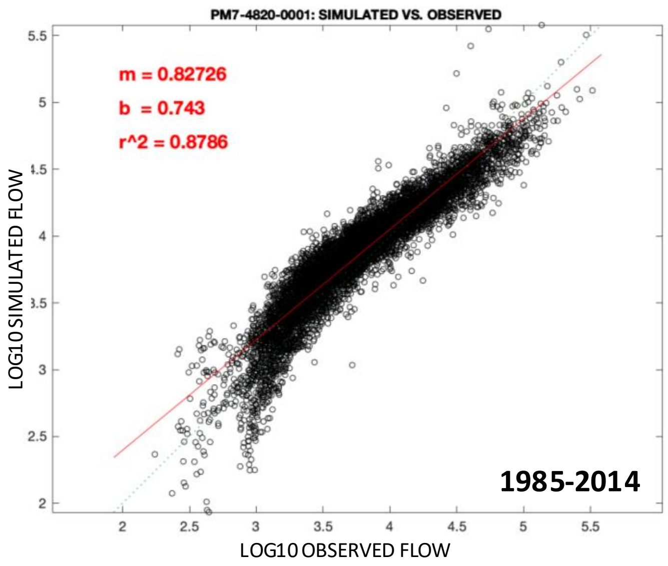
- **Simulated flow for years 2018 onwards were running low for several stations with NLDAS2 precipitation.**

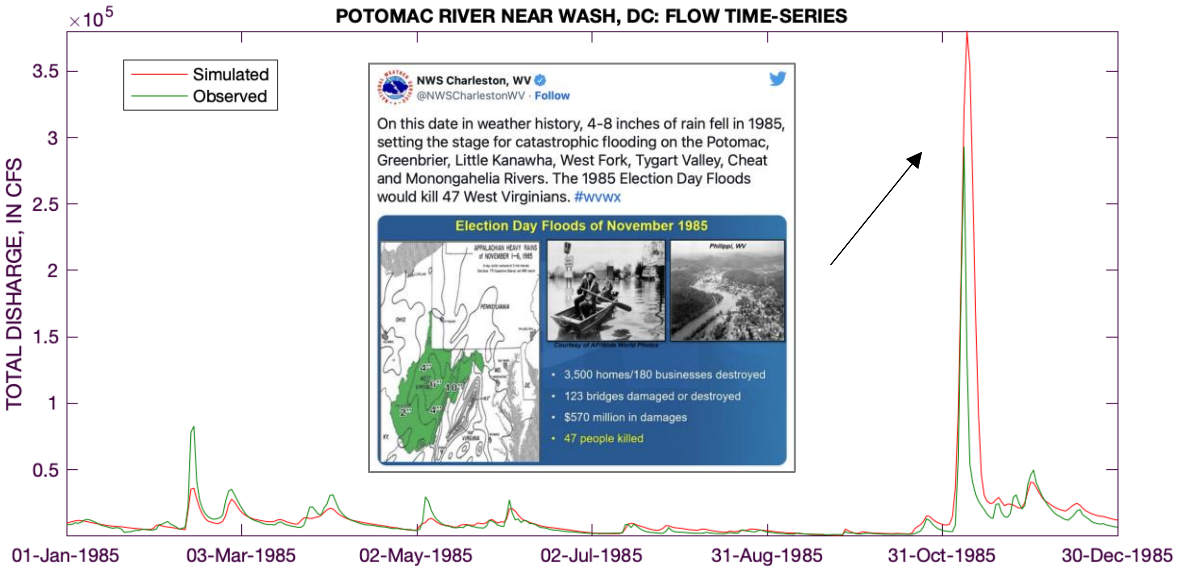
Major Rivers	NLDAS2	PRISM
Susquehanna Marietta PA	0.9375	**0.9433**
Potomac Washington, DC	0.8928	**0.9270**
James Cartersville, VA	0.8178	**0.9054**
Rappa. Fredericksburg, VA	0.8052	**0.9309**
Appomattox Matoaca, VA	**0.8883**	0.8467
Pamunkey Hanover, VA	0.8058	**0.8124**
Mattaponi Beulahville, VA	0.7450	**0.7916**
Patuxent Bowie, MD	0.8232	**0.8662**
Choptank Greensboro, MD	0.5876	**0.7293**



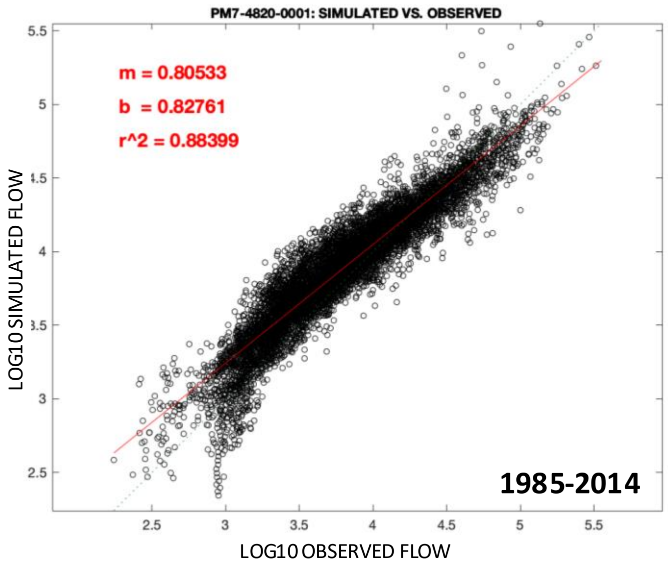
PRISM improves simulation of large events

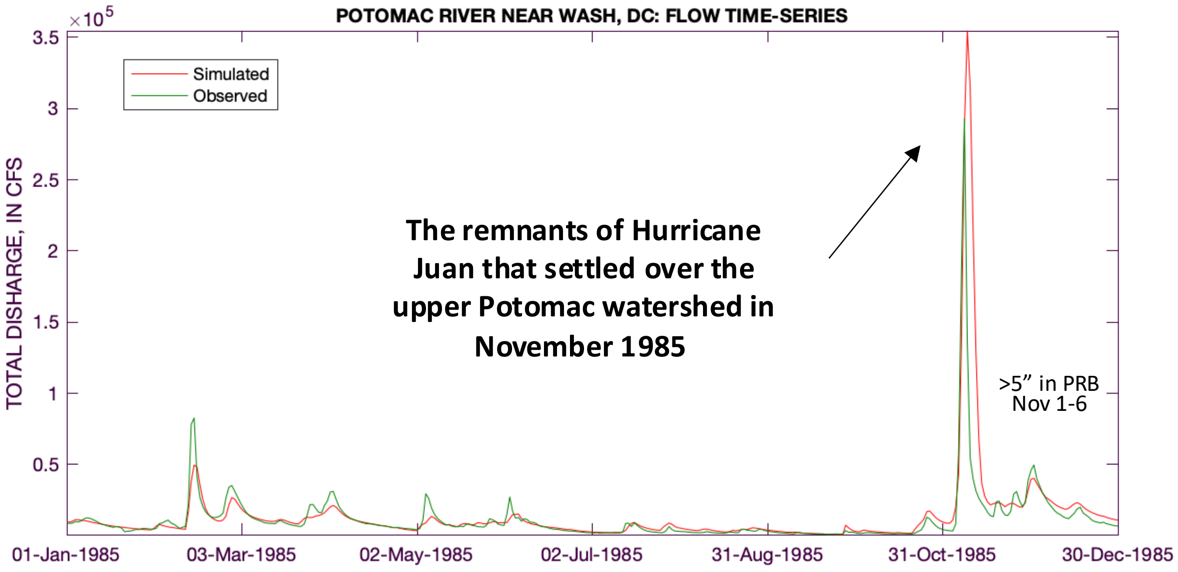
NLDAS2





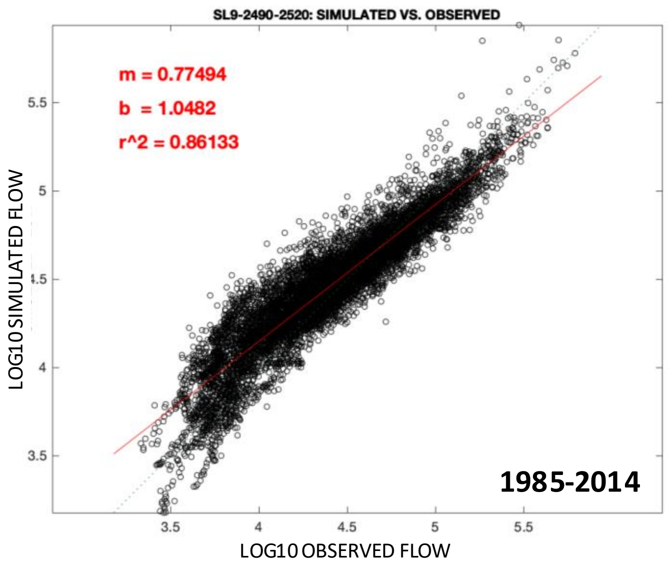
PRISM & parameters

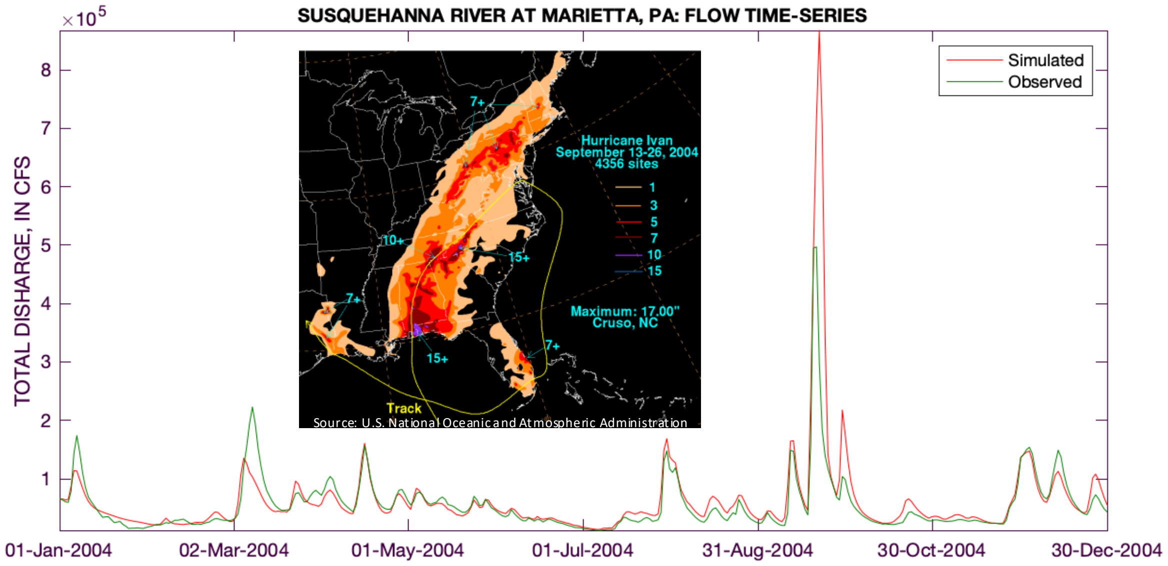




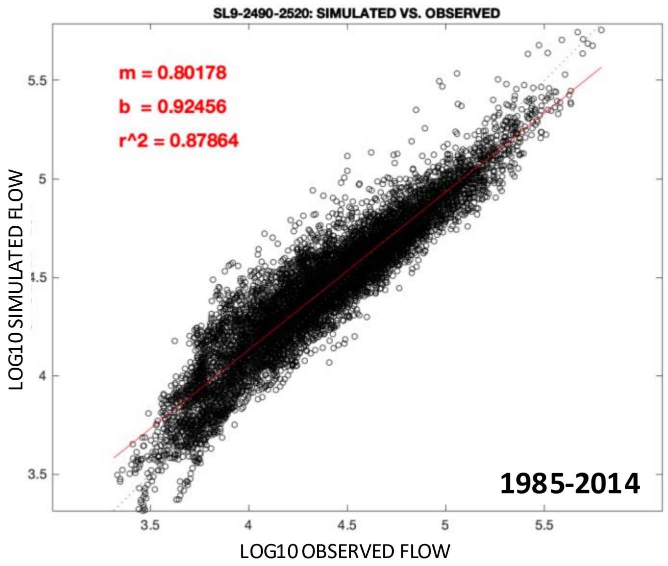
PRISM improves simulation of large events

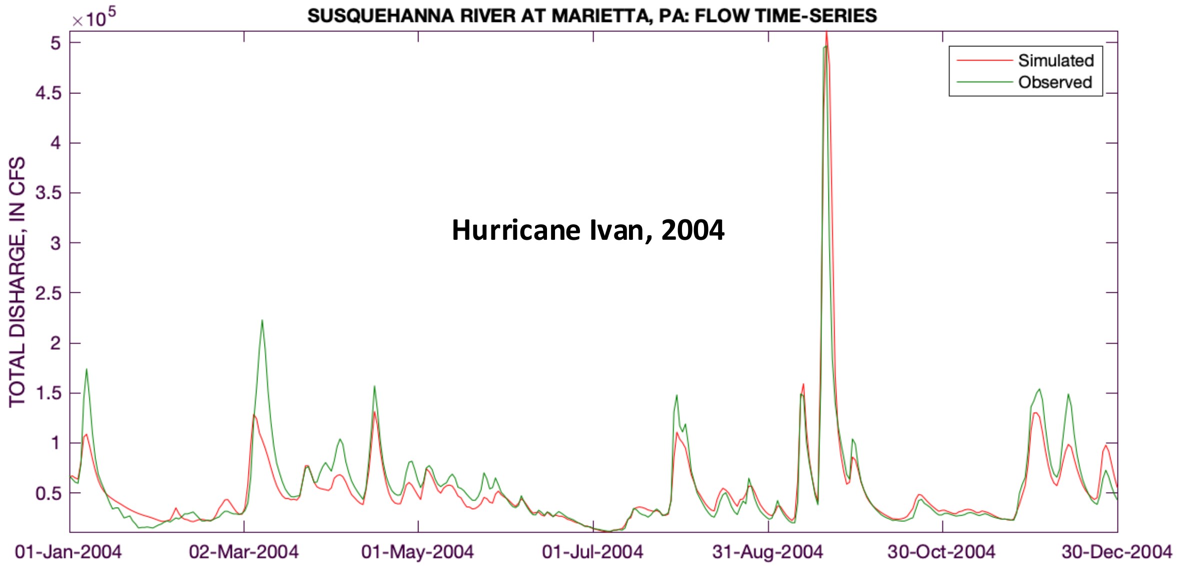
NLDAS2





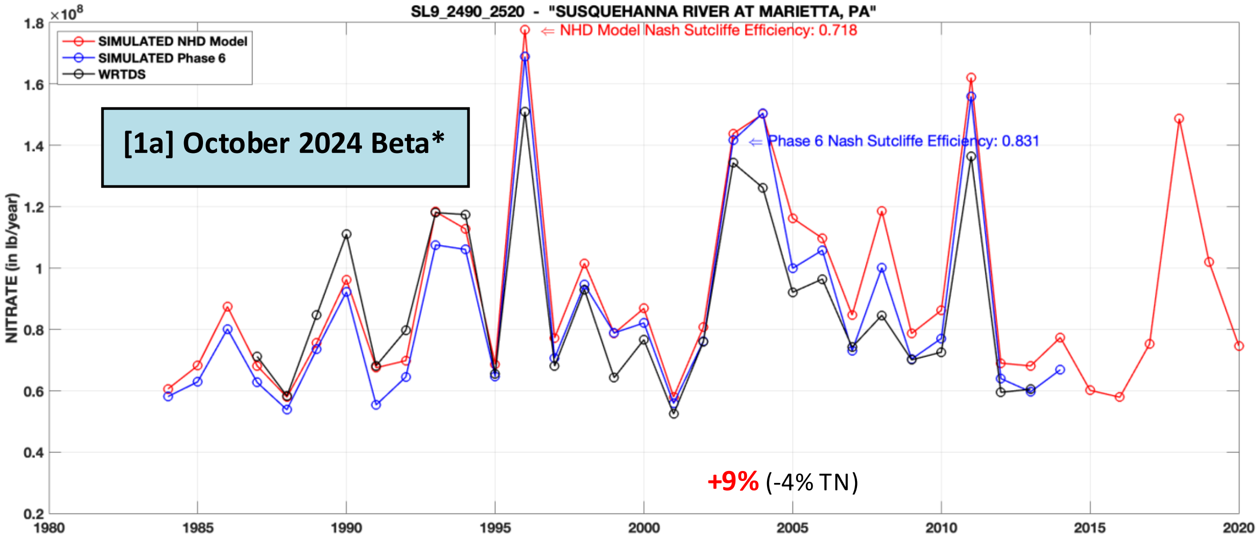
PRISM & parameters

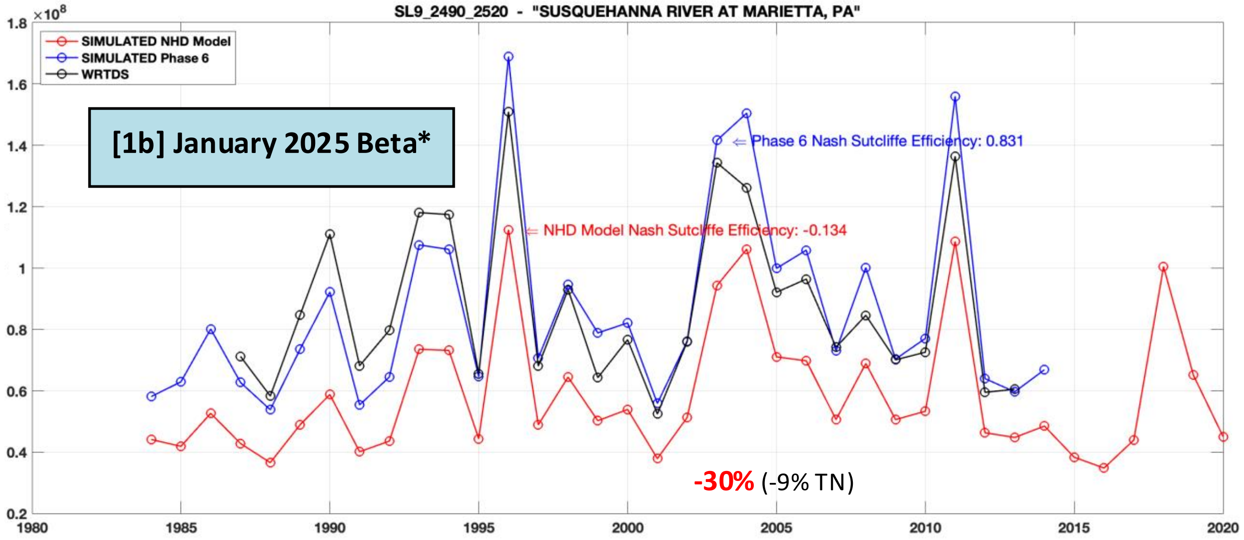




Adding nitrogen speciation in Phase 7 improved nitrate...

- **We identified a discrepancy in nitrate loads simulated in December 2024 and January 2025 beta versions.**
  - **Nitrate loads are substantially underestimated in recent beta versions.**

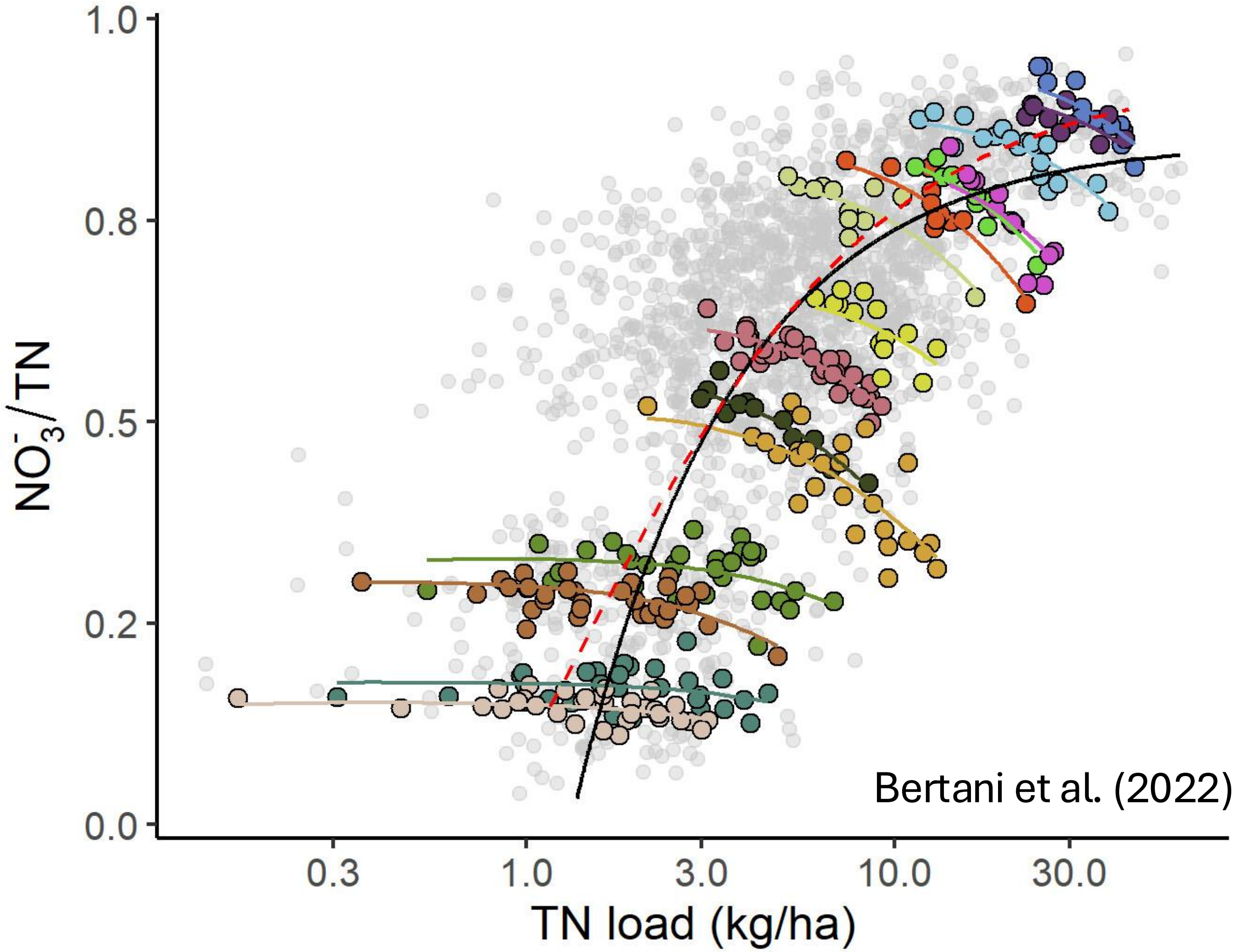




*isolated calibration runs with only difference in CalCAST outputs

Nitrogen speciation (revisited...)

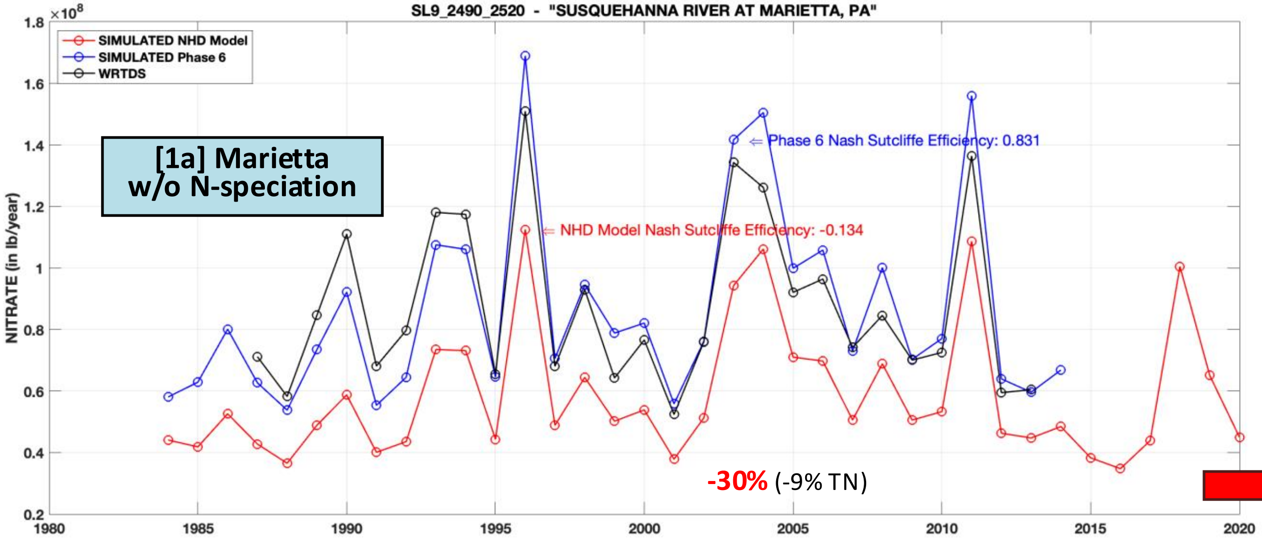
- Bertani et al. (2022) applied hierarchical modeling to establish relationship between annual nitrate (NO3) fraction and log-transformed annual nitrogen (TN) load estimated at 101 riverine stations in the Chesapeake Bay watershed.
- Red dashed line estimate how the long-term average NO3 fraction is predicted to vary.
- Colored lines show predicted NO3 fraction from station-specific regressions.

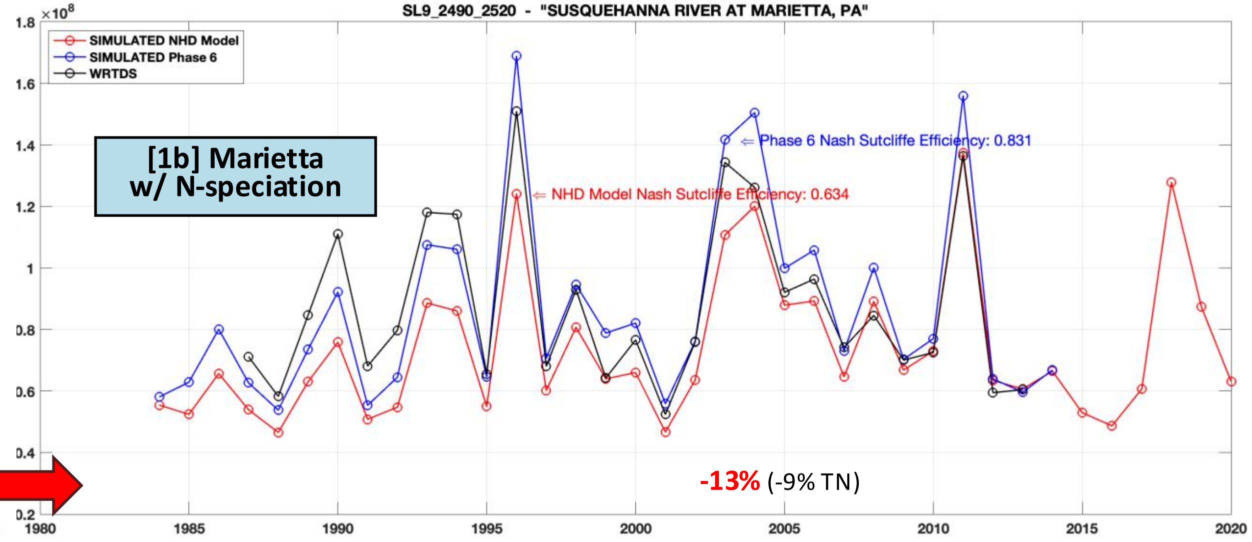


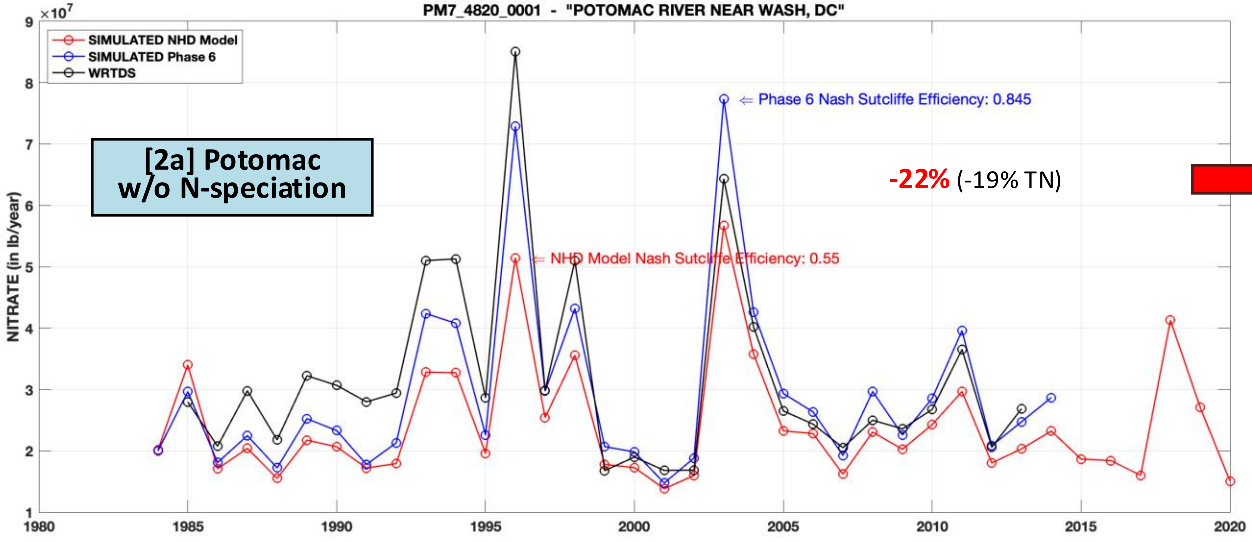
Bertani, I., G. Bhatt, G.W. Shenk, and L.C. Linker. 2022. "Quantifying the Response of Nitrogen Speciation to Hydrology in the Chesapeake Bay Watershed Using a Multilevel Modeling Approach." Journal of the American Water Resources Association 58 (6): 792–804. https://doi.org/10.1111/1752-1688.12951.

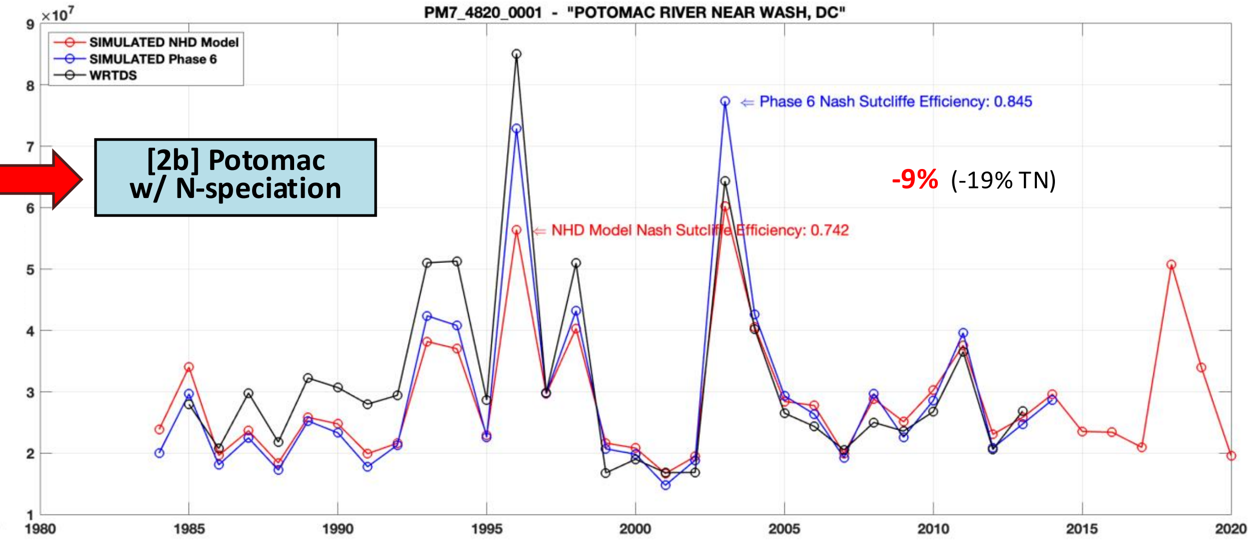
Similar to Phase 6, we added this emergent behavior of N-speciation in Phase 7 at the interface of land and aquatic transport models.

Adding nitrogen speciation in Phase 7 improved nitrate

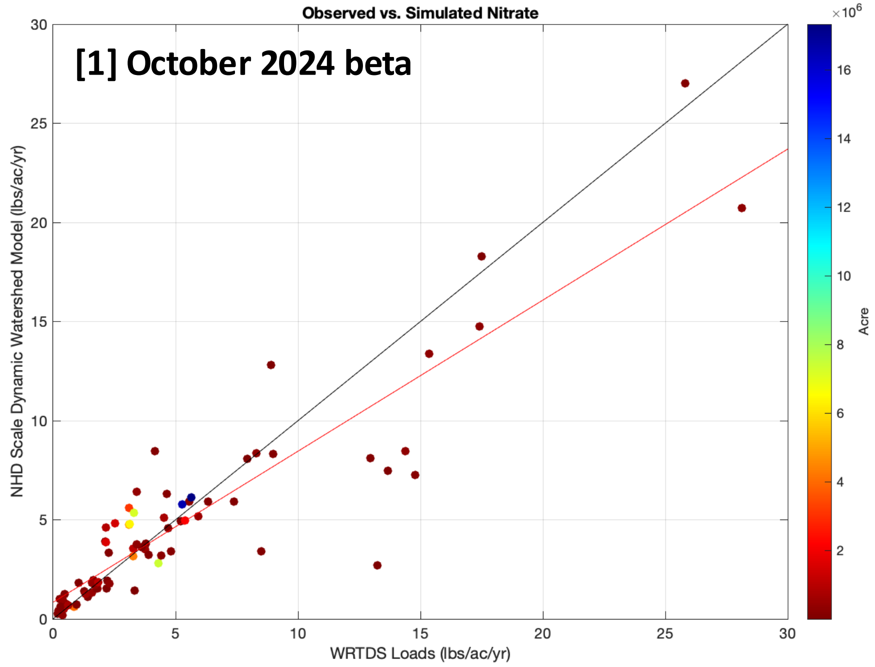


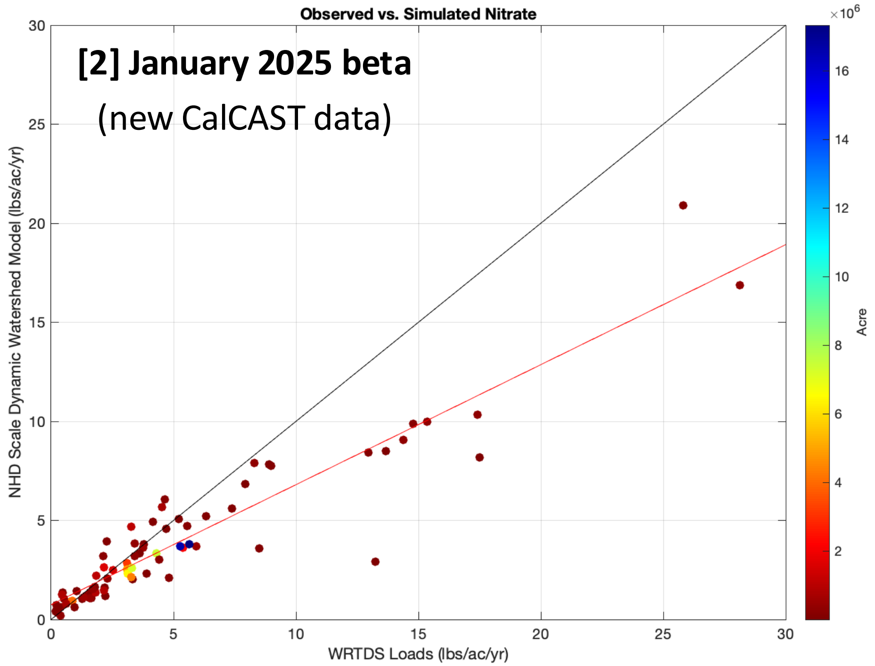


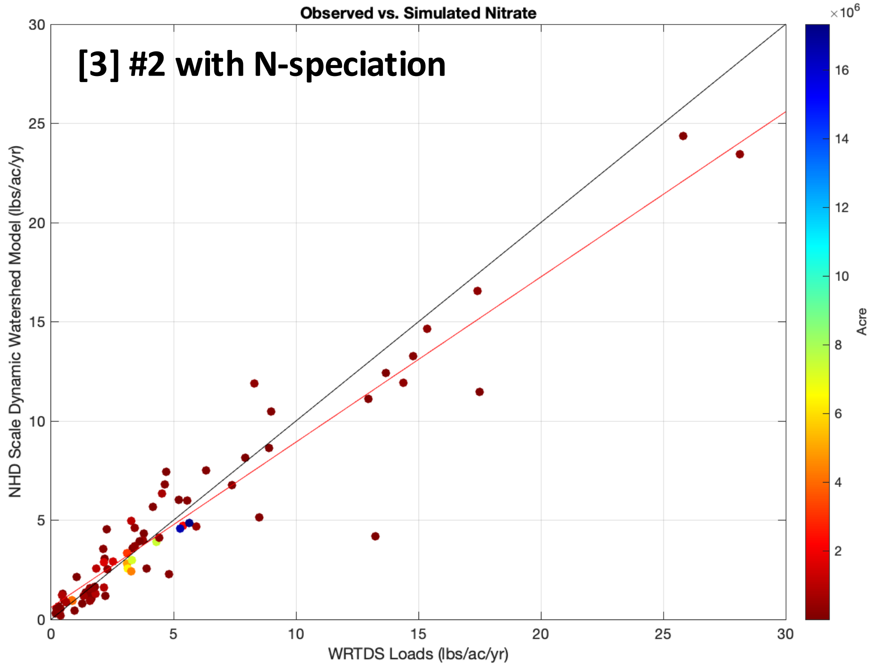




Tracking change in mean annual nitrate (lb/ac/yr)

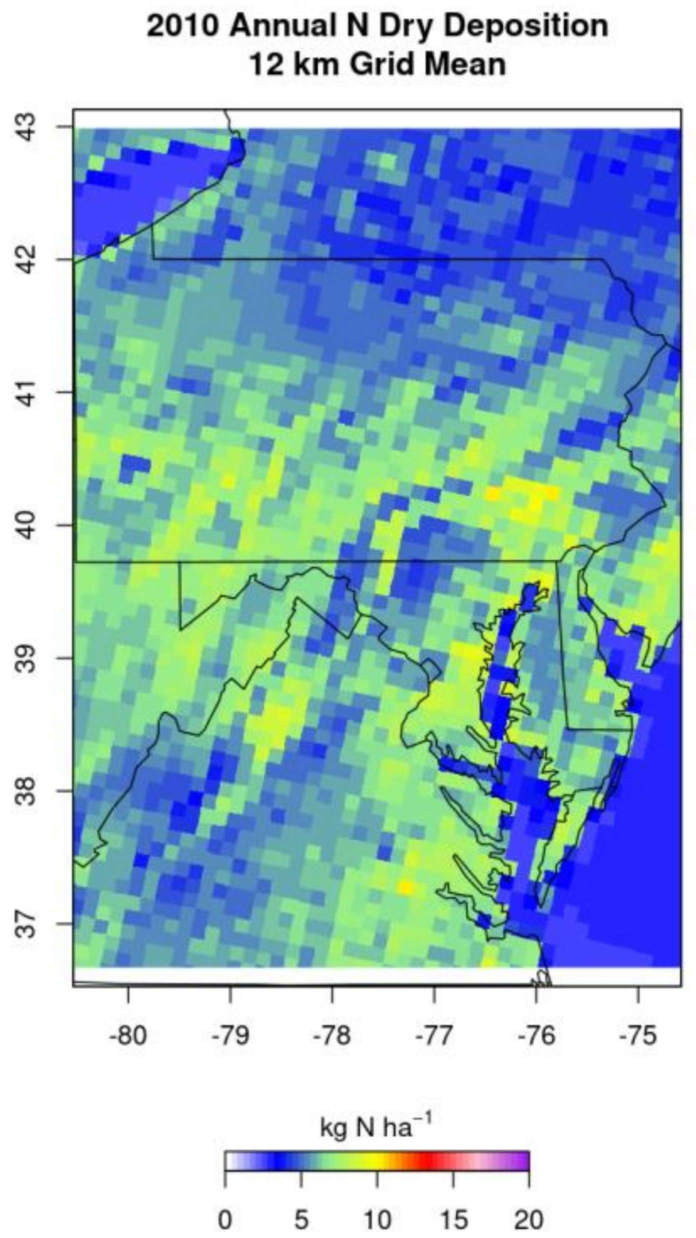




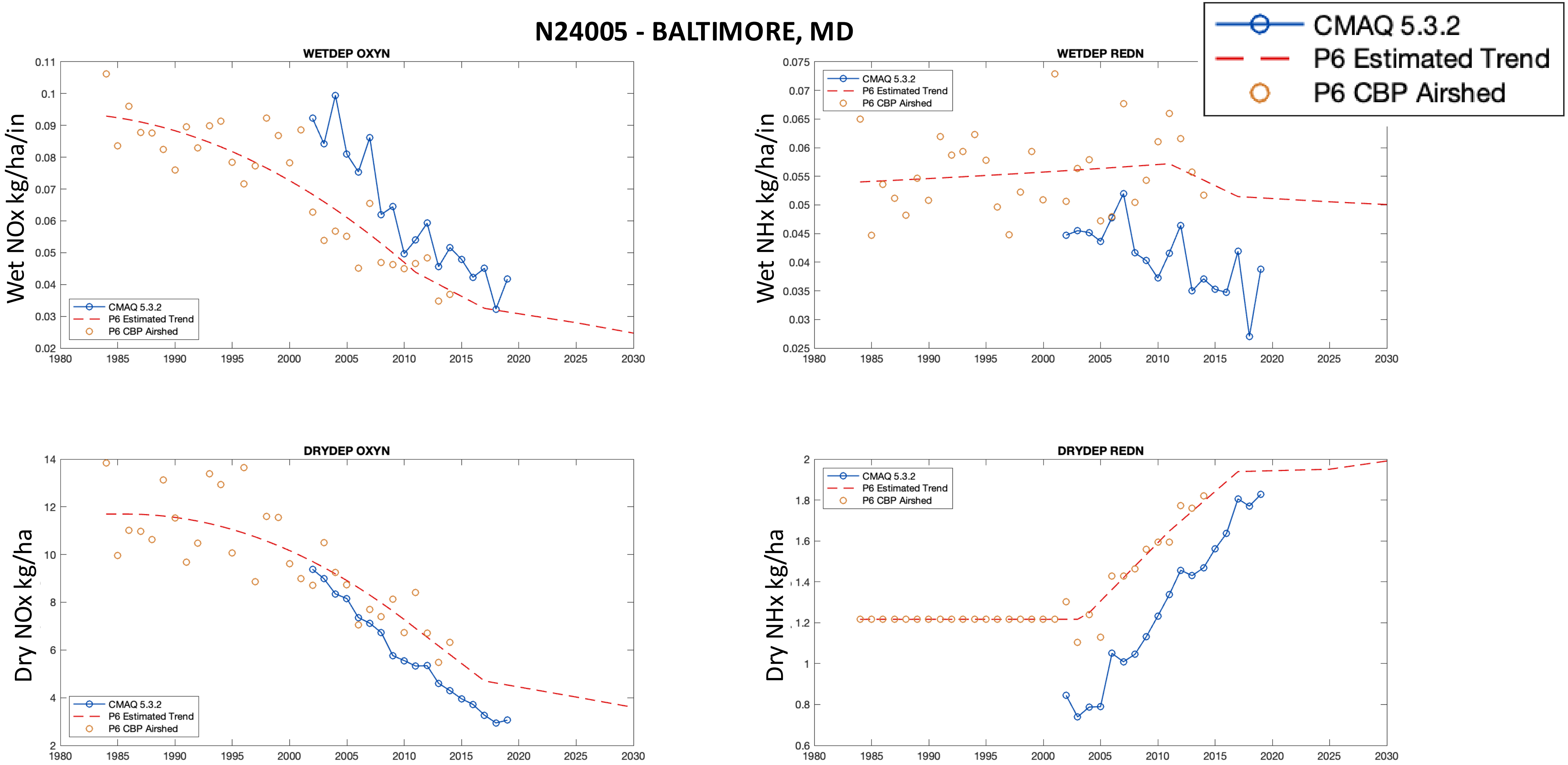


New CMAQ data in Phase 7 CBP Airshed N loads

- CBP Phase 6 airshed model has atmospheric N data for 1985-2014 and trends for 1985-2030.
- We received latest wet and dry, oxidized and reduced N-deposition data at 12-km spatial resolution from CMAQ model version 5.3.2 [Jesse Bash, EPA].
- Spatial coverage includes both watershed and estuarine model domains for the 2002 to 2019 period.
- We developed scripts for the processing of loads and performed comparative analyses of CBP P6 airshed and CMAQ deposition estimates for both watershed and tidal water domains.



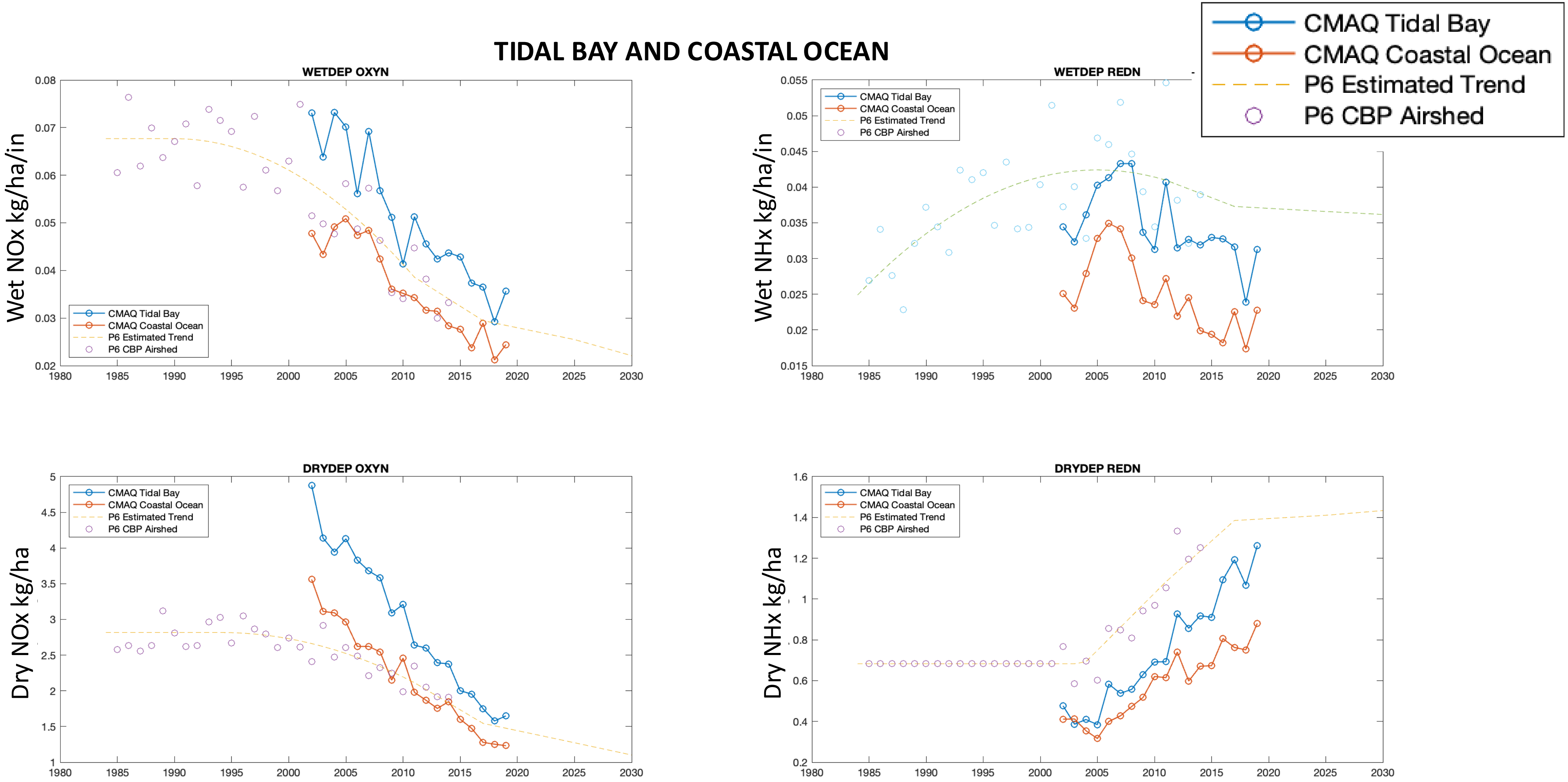
We need a method to effectively blend the datasets...



We need to convene a small group to get expert inputs to come up with a method for most appropriate blending of datasets.

We need a method to effectively blend the datasets...

TIDAL BAY AND COASTAL OCEAN

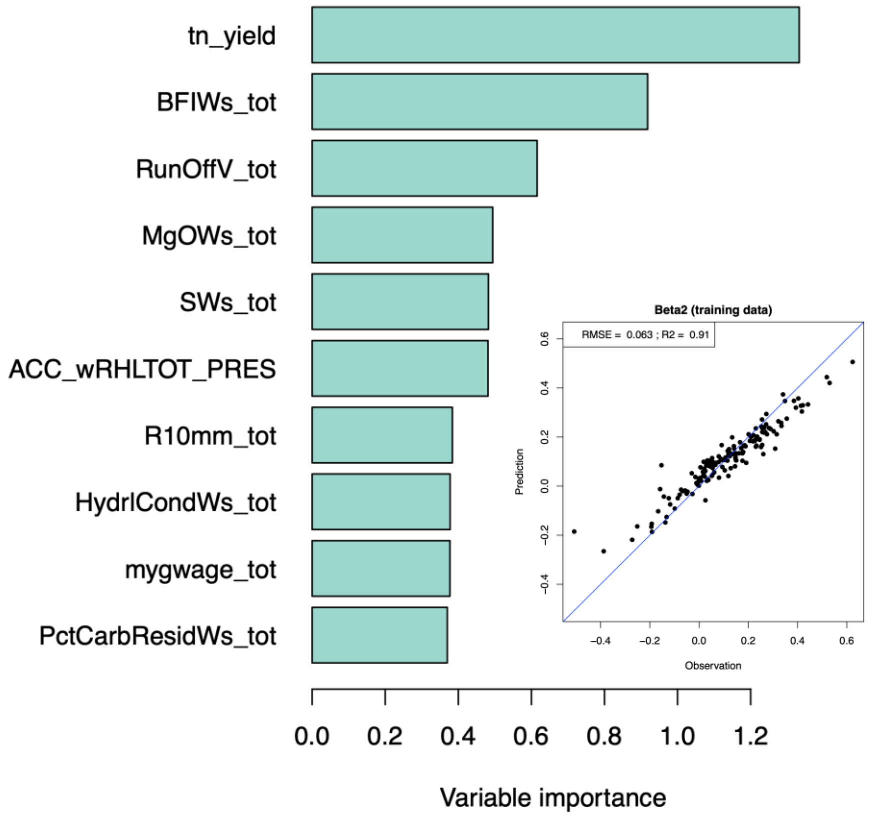


We need to convene a small group to get expert inputs to come up with a method for most appropriate blending of datasets.

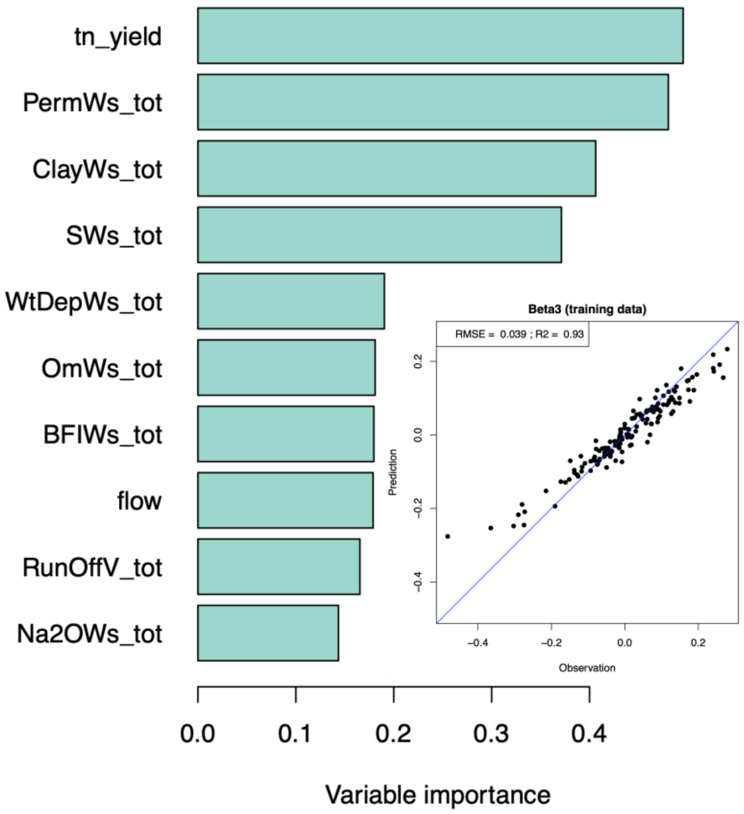
Other general progress are on track…

- **We are making good progress on Beta parameters for TN, TP, and SS [Qian Zhang, UMCES].**

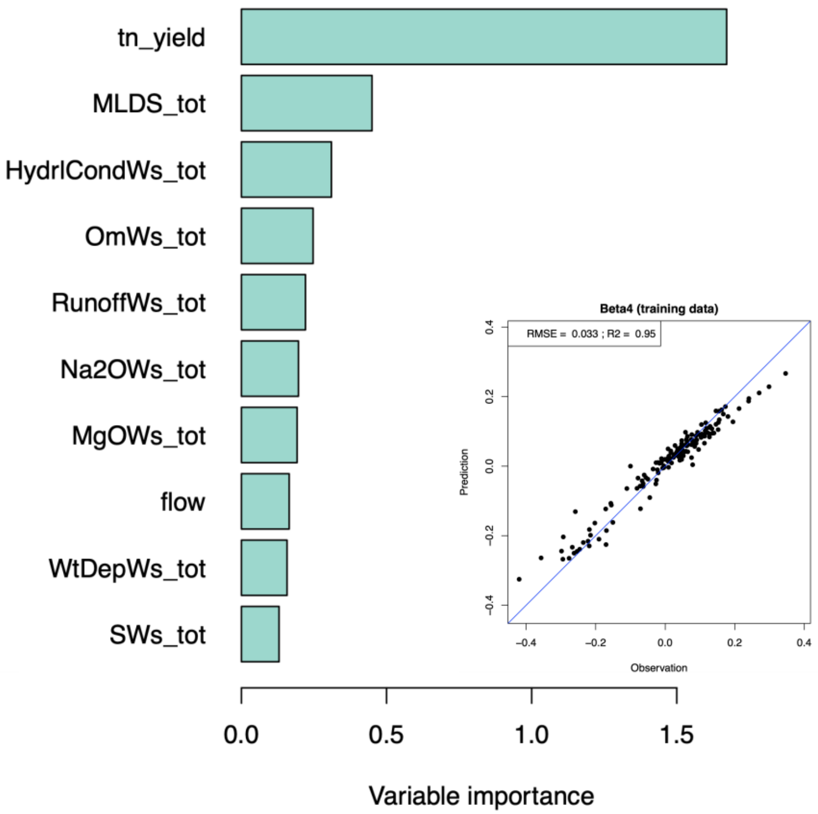
β2 Random Forest model



β3 Random Forest model



β4 Random Forest model



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

Summary

1. We updated beta versions and linkage of incrementally refined watershed model flows and loads with the estuarine model.

- E.g., refined CalCAST data for phosphorus; hydrology model calibration; simulation of nitrogen speciation; NetCDF file; evaluation of model performance in collaboration with the MBM team;

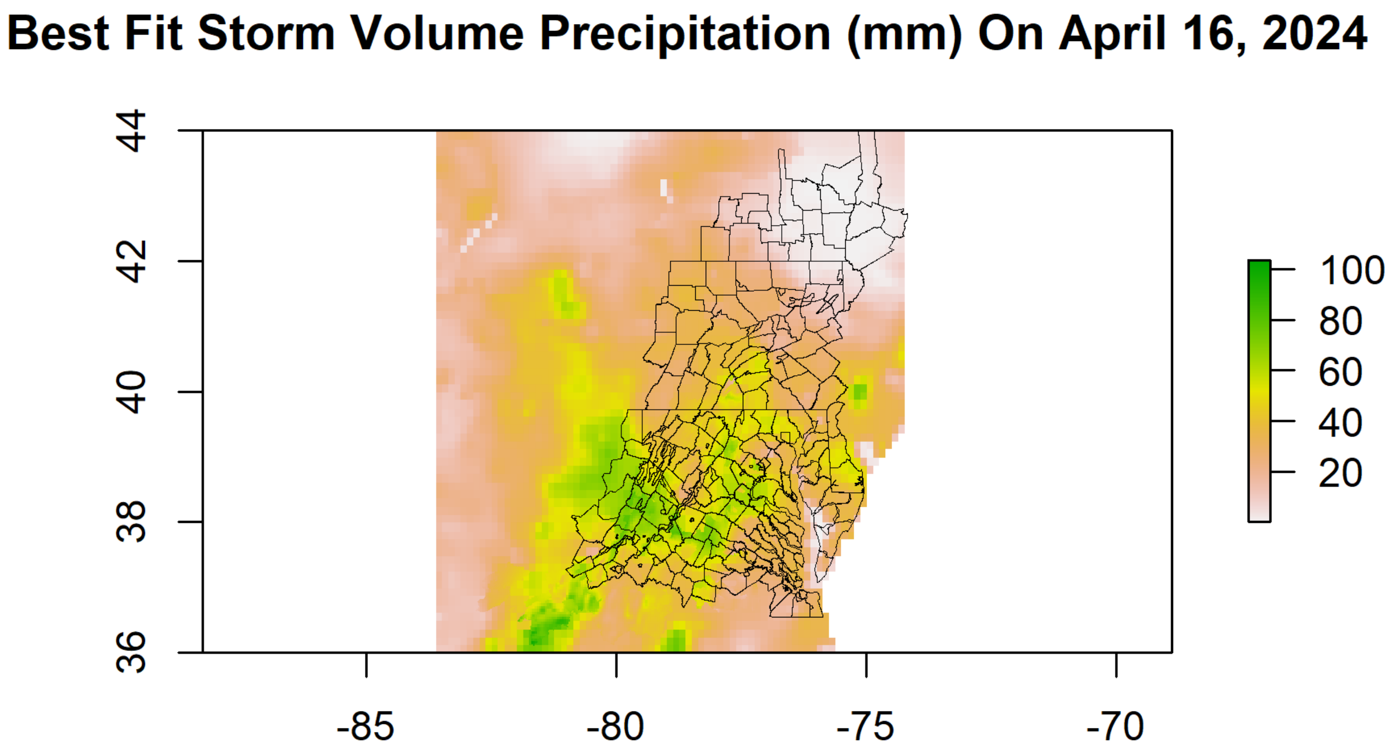
>> Next Steps for the Phase 7 Dynamic Watershed Model (DWSM)

2. We have shifted towards completeness of the model: (a) incorporation of inputs (BMPs; afo/cfo loads); (b) model parameters (beta parameters); (c) calibration methods (RIM loads); (d) linkage with the MBM and MTMs (atmospheric inputs, tracking progress).

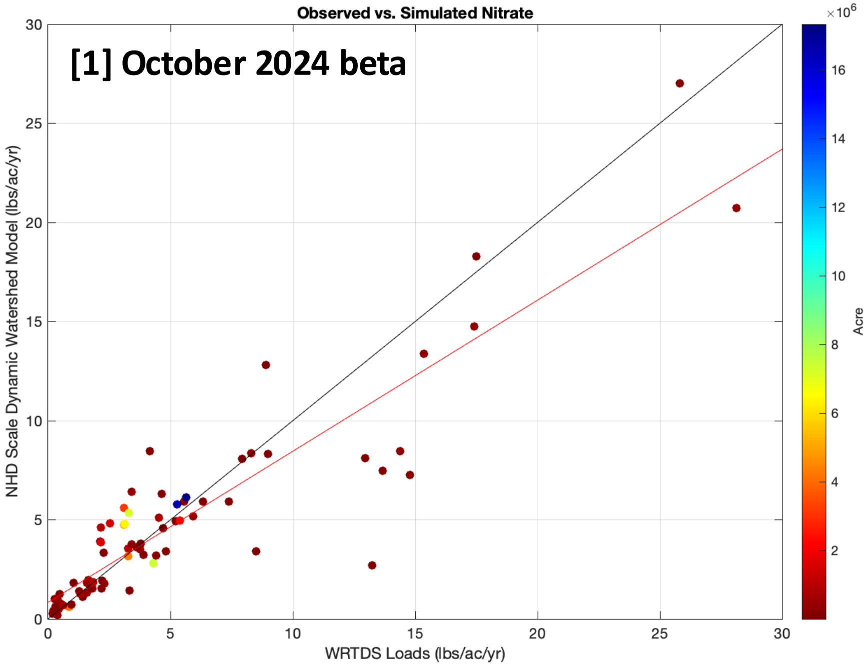
Appendices

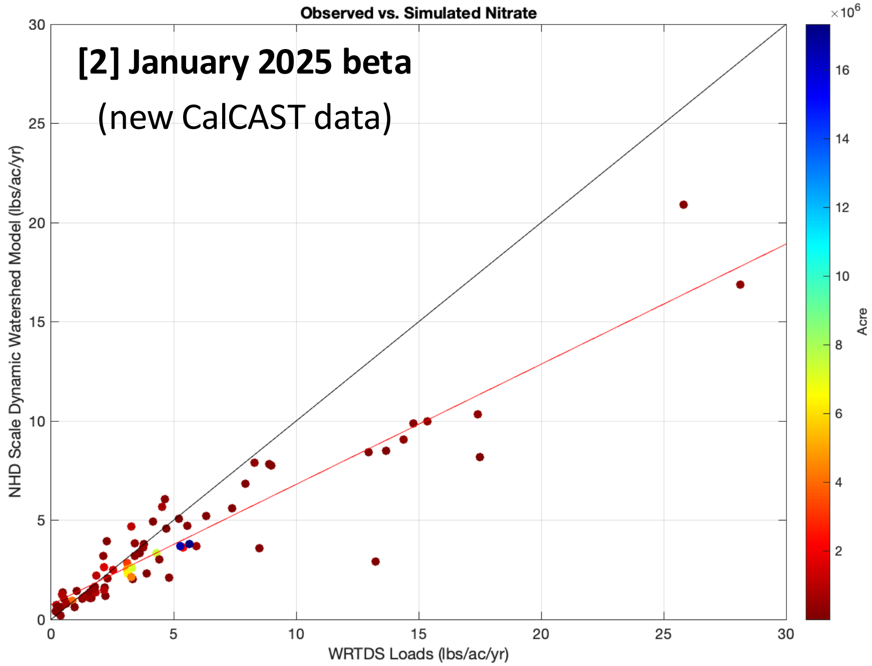
Amalgamate Multiple Sources of Precipitation

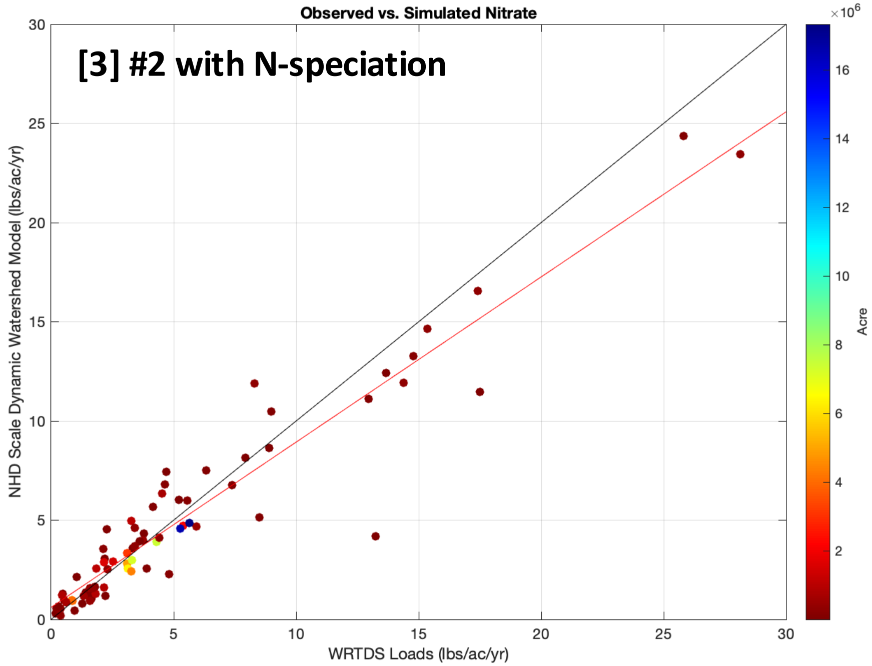
- "Precipitation Fidelity" analysis (missing/extra storms, water balance anomalies, …) at USGS gage drainage basins.
- Identify best daily precipitation source.
- "Amalgamate" the best fit for each gage into a single daily raster, then daily to hourly.
- Extract precip at each Chesapeake Bay land segment (244 total)
- Convert precipitation files to model inputs to **.wdm* files.
- We can amalgamate 3 data sources in under a day on a single 8-threaded machine.



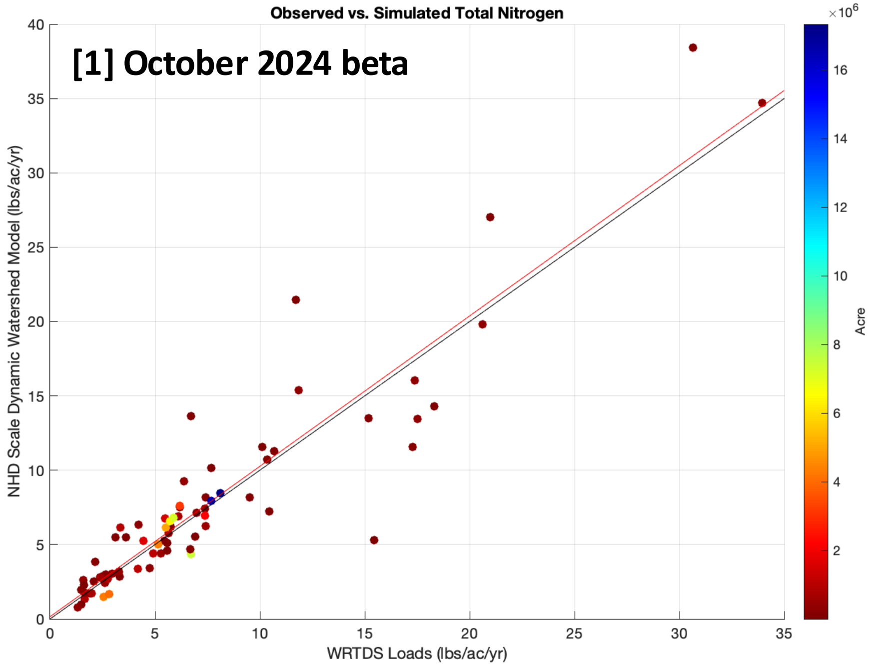
Tracking change in mean annual nitrate (lb/ac/yr)

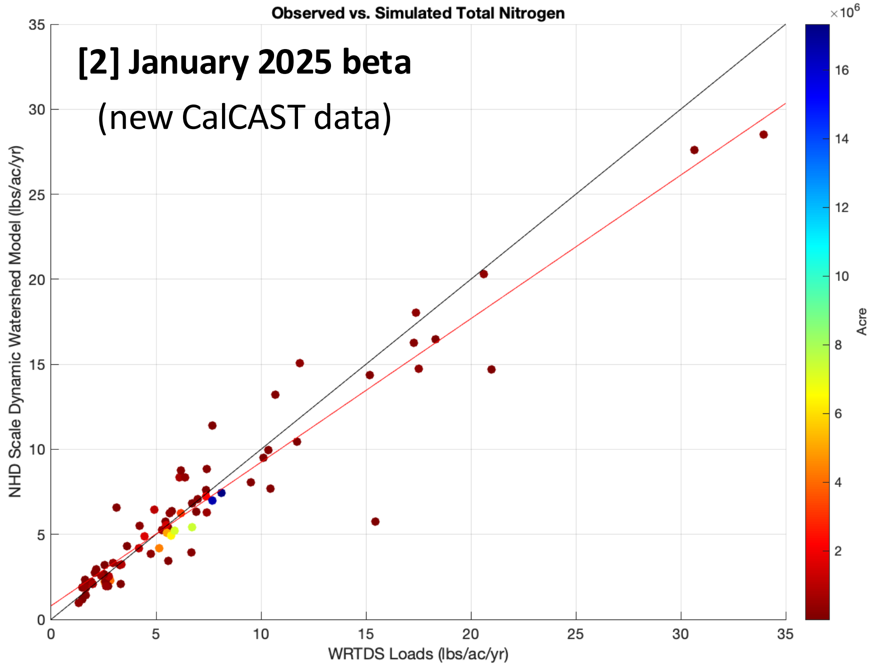


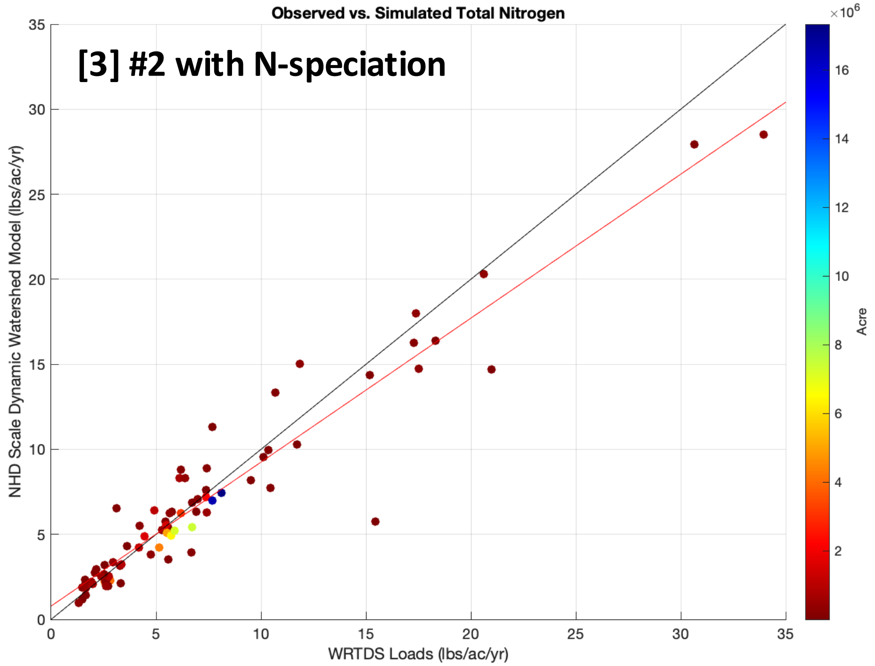




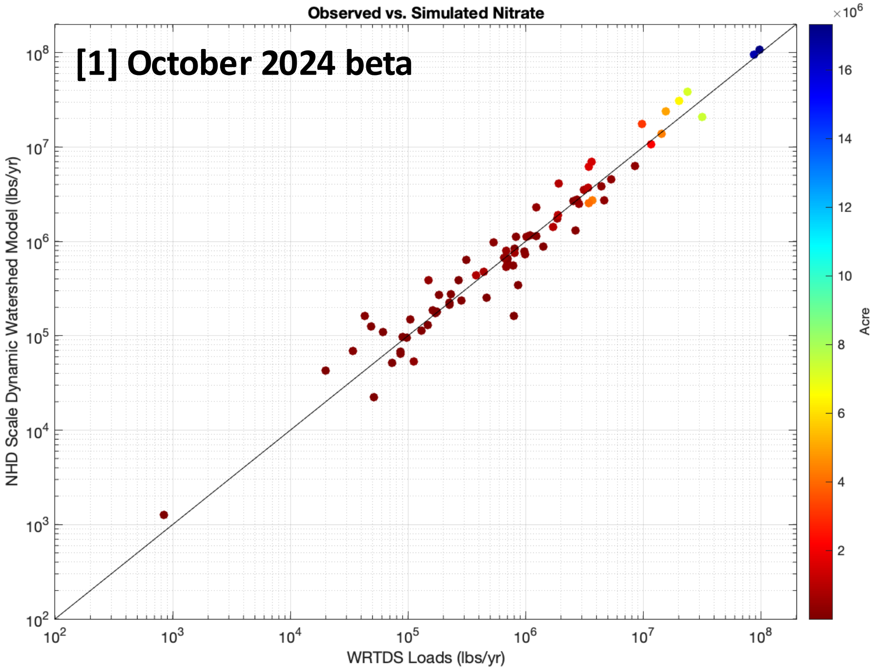
Tracking change in mean annual nitrogen (lb/ac/yr)

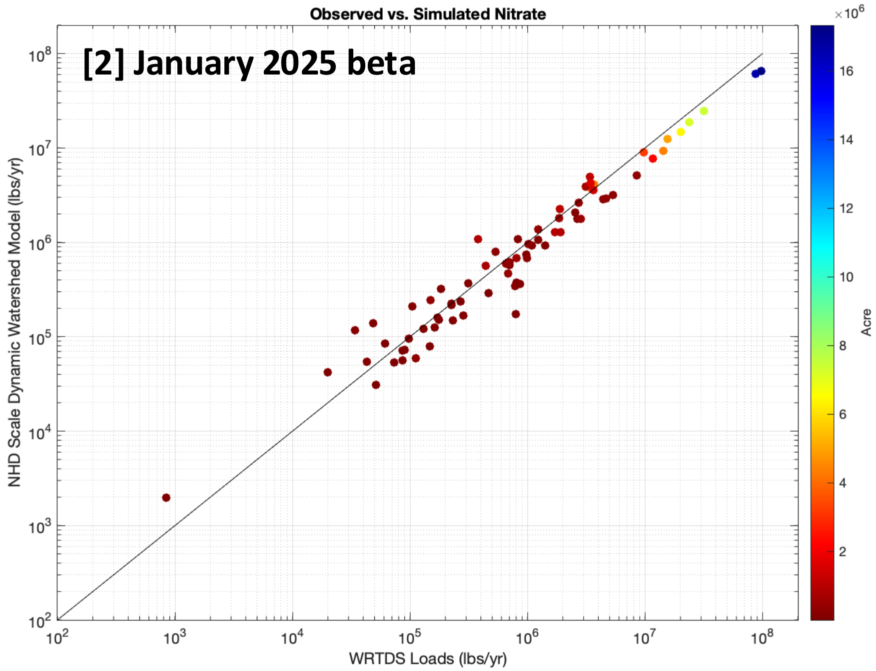


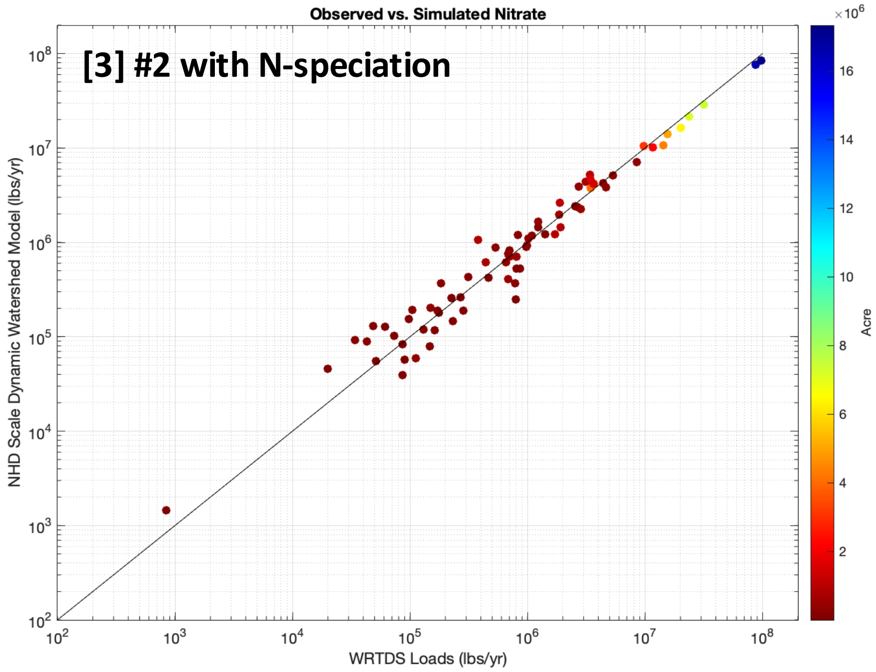




Tracking change in mean annual nitrate (lb/yr)

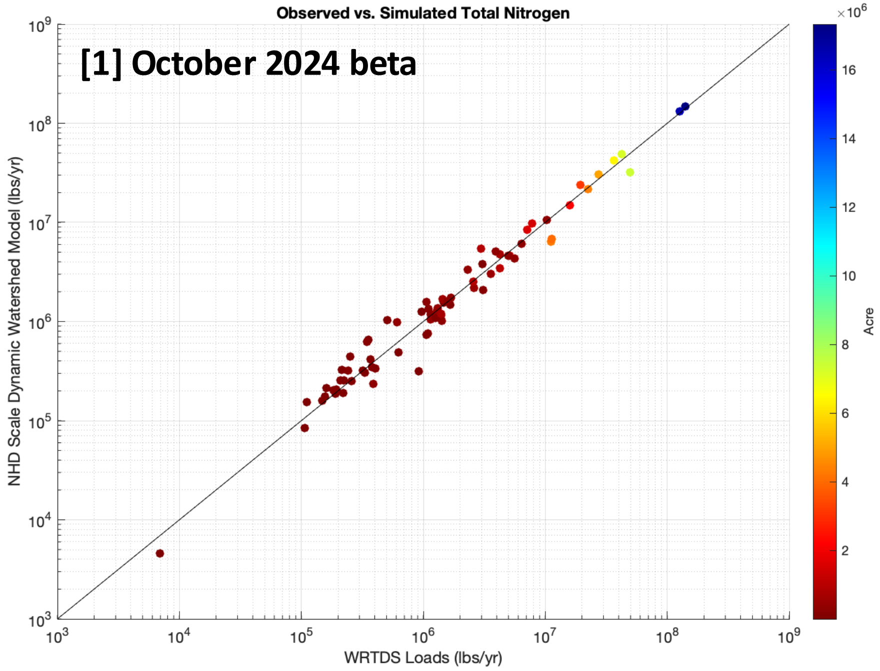


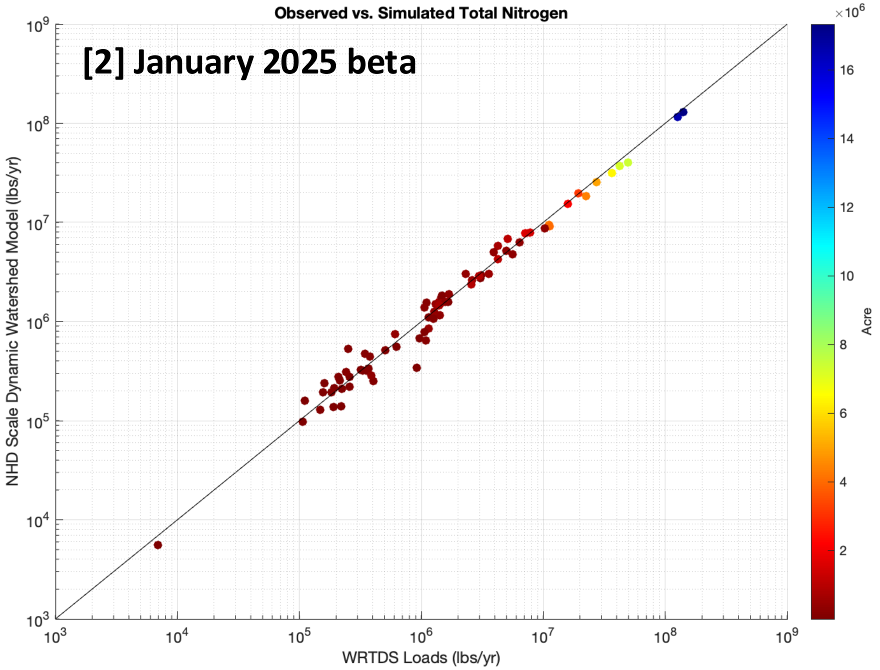


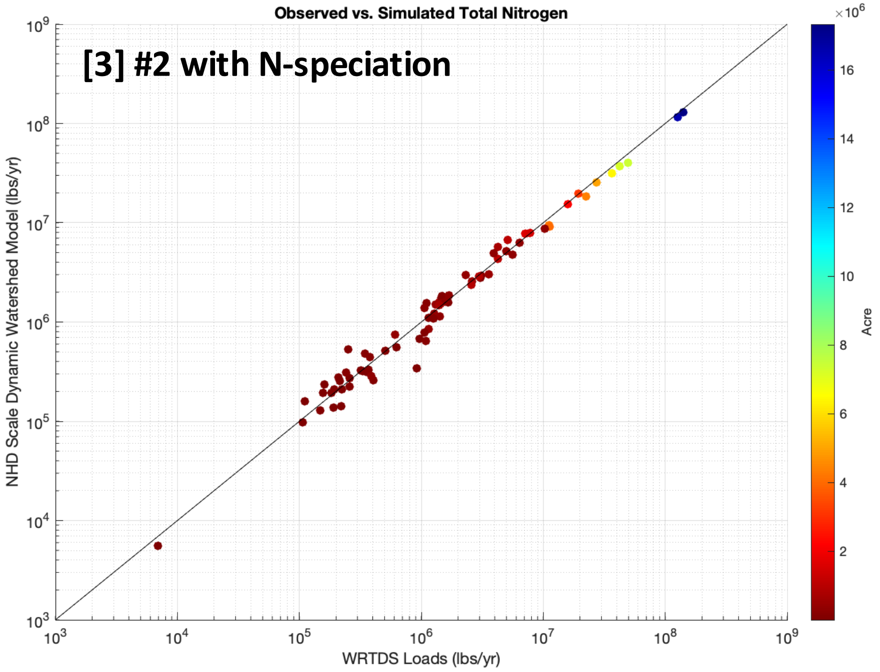


Underestimation in [3] may be linked to total nitrogen shown on the next slide

Tracking change in mean annual nitrogen (lb/yr)

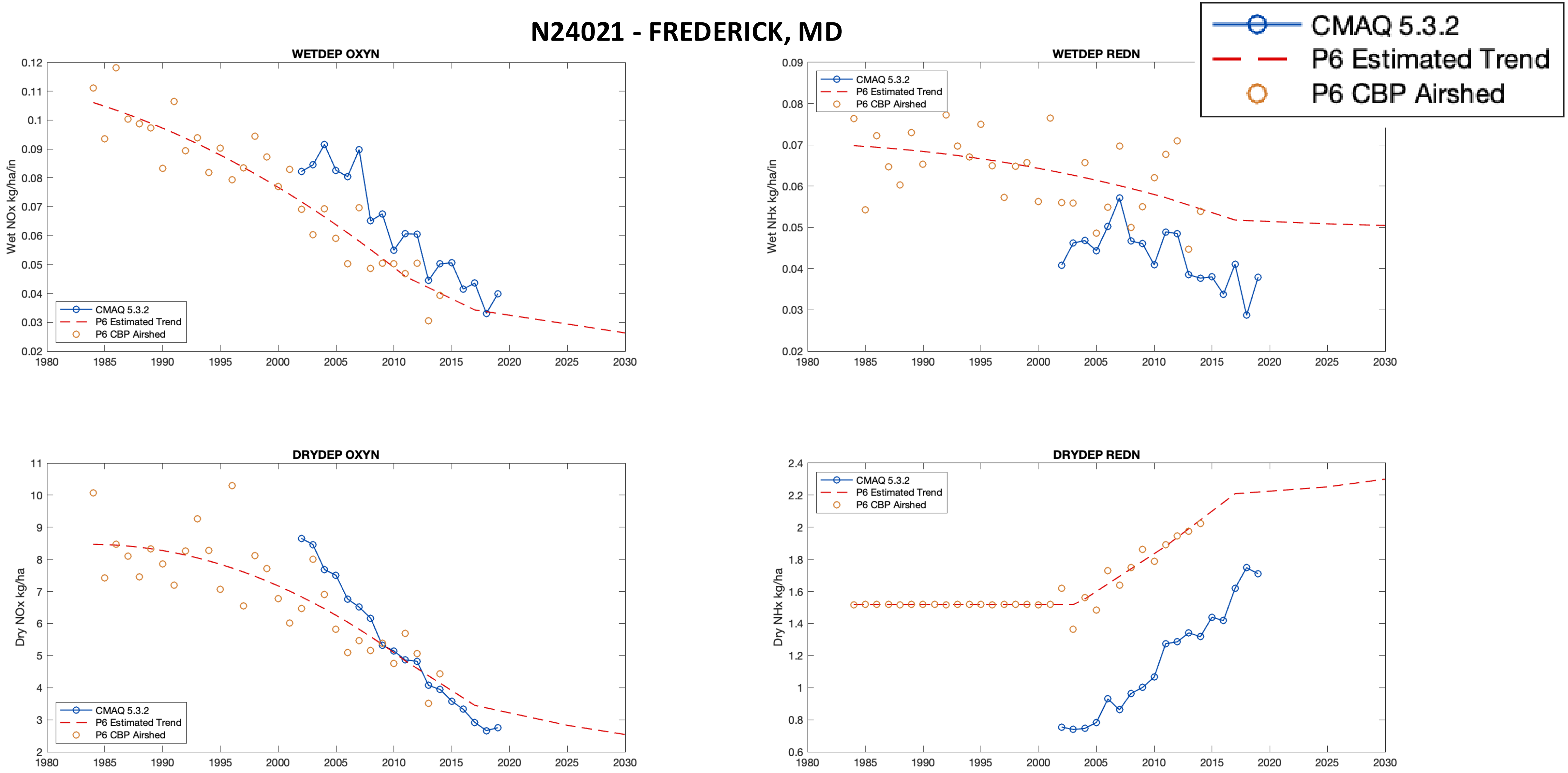






Underestimation in nitrate [3] on previous slide may be linked to total nitrogen

We need a method to effectively blend the datasets...



We need to convene a small group to get expert inputs to come up with a method for most appropriate blending of datasets.