Simulating the effects of intra-monthly rainfall variability on Chesapeake Bay water quality under a changing climate

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Motivation

- Climate models project that the intensity and frequency of rainfall events in the northeastern United States are likely to increase [1].
- Extreme rainfall events can disproportionately affect discharge (Q) as well as export of nitrogen (N), phosphorus (P), and suspended solids (SS) to the Chesapeake Bay [2].
- Previous simulations of the effect of climate change on Chesapeake Bay water quality have not studied the importance of intra-monthly rainfall variability [3].

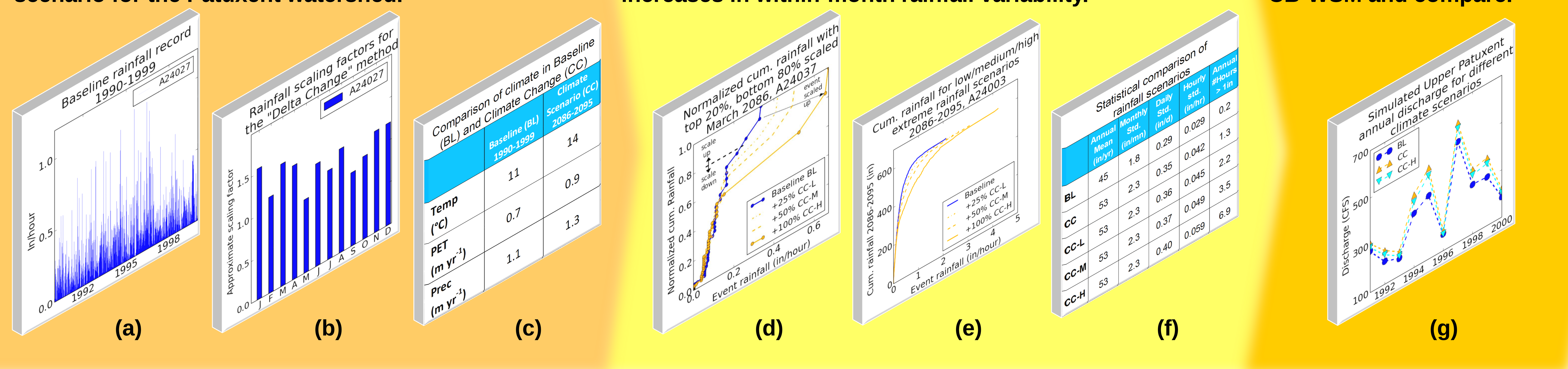
Research Question: How will changes in intra-monthly rainfall variability affect simulations of the impact of climate change on N/P/SS loading to the Chesapeake Bay?

Methods

1. Obtain 2086-2095 "baseline" climate scenario for the Patuxent watershed.

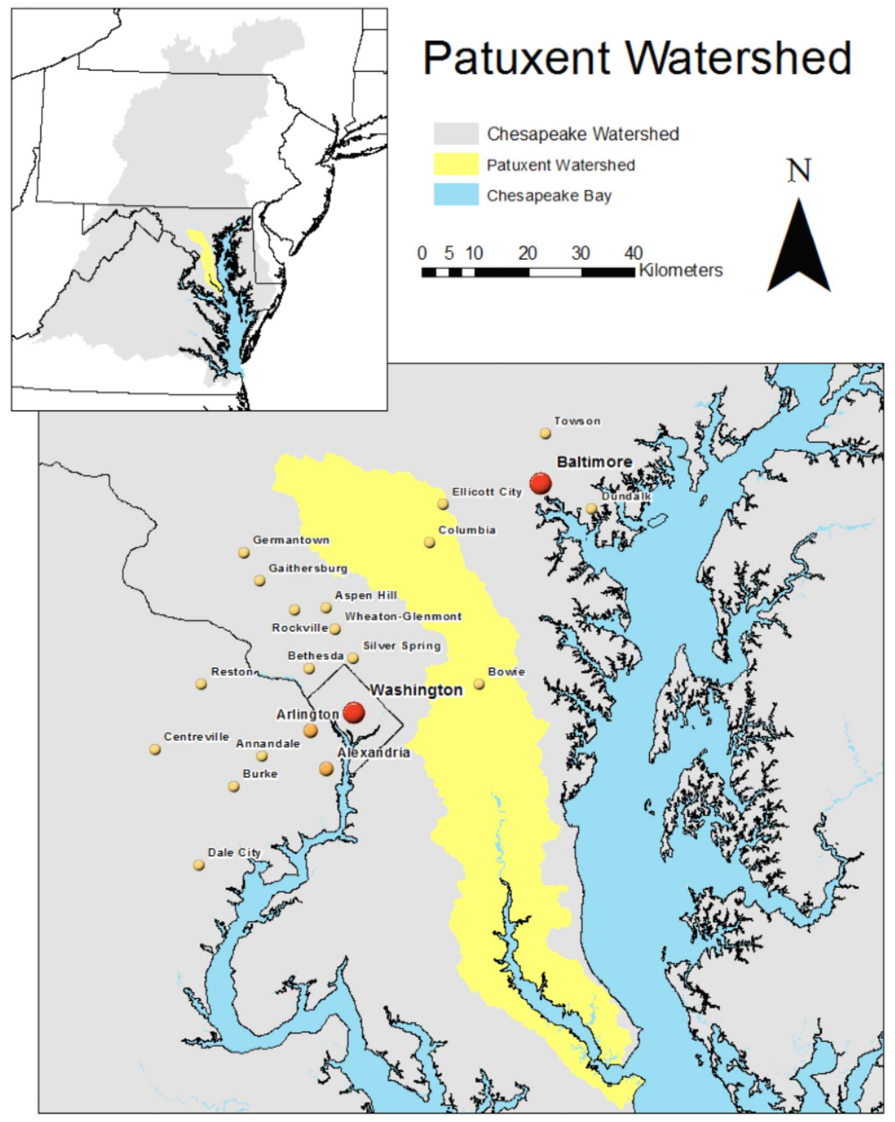
2. Create three new scenarios with low / medium / high increases in within-month rainfall variability.

3. Run scenarios with the CB-WSM and compare.



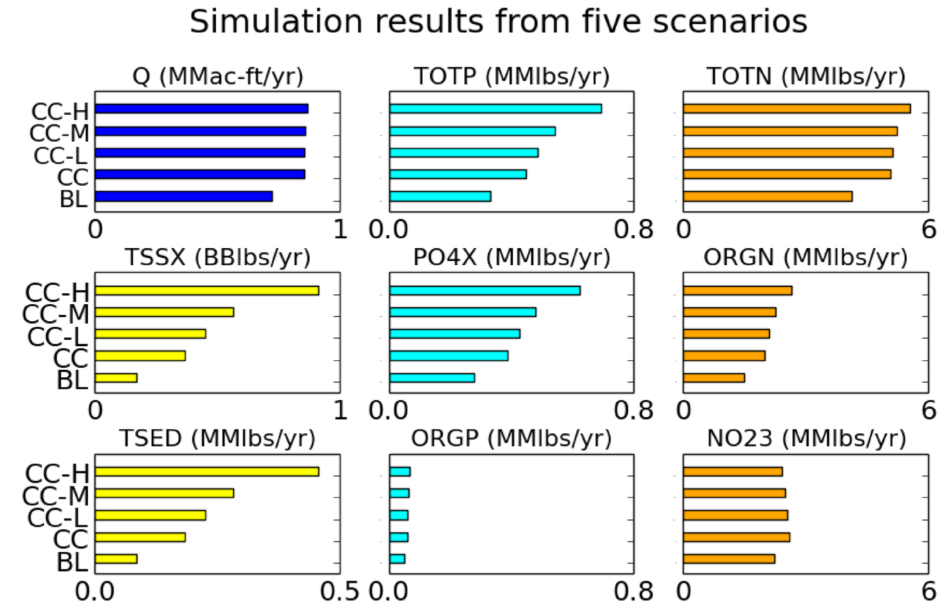
We begin with baseline (BL) 1990-99 record for temperature and precipitation **(Fig. a)** from the Chesapeake Bay Community Watershed Model Phase 5.3.2 (CB-WSM) [4]. From the CB-WSM database we extract a 2086-95 climate scenario developed by USGS using the "delta change method" [5] derived from the BCCR-BCM2.0 Global Climate Model [6]. The method multiplies the precipitation record by a month-specific scaling factor **(Fig. b)**. The resultant climate scenario (CC) has approximately 20% more annual rainfall than the BL scenario **(Fig. c)**. Future temperature and PET were also simulated, as reported in [3]. To simulate extreme rainfall variability, for each month of the CC scenario, we increase the largest hourly rainfall events that contribute 20% of the rainfall volume by a +25% (C+C-L), +50% (CC-M), and +100% (CC-H) extreme rainfall multiplier. We uniformly scale down the smaller rainfall events to keep the total monthly rainfall constant **(Fig. d)**. Next we reassemble the modified monthly rainfall data into complete CC-L, CC-M, and CC-H rainfall scenarios **(Fig. e)**. We do a statistical comparison and find for the three extreme scenarios that the month to month standard deviation is constant, but hour to hour standard deviation significantly increases, as expected **(Fig. f)**. Finally we use the CB-WSM, with the TMDL calibration values [4], to compare the five scenarios' performance **(Fig. g)**.

Study Site



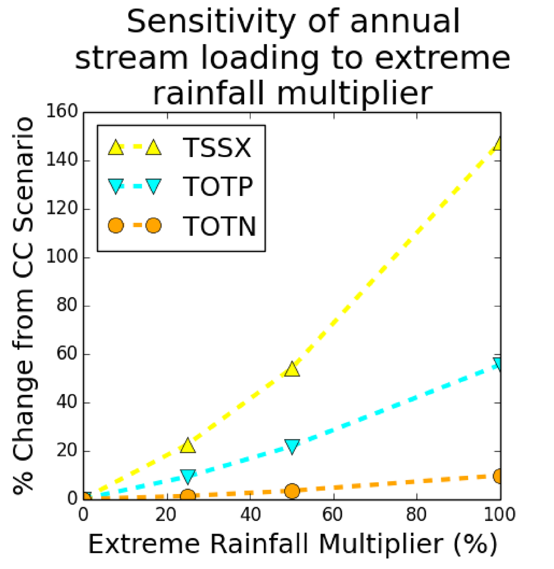
Simulation Results

I The bottom figure shows simulation results for the increase in Q/N/P/SS loading from the Patuxent Watershed to the Chesapeake Bay under the five scenarios described above. We see that discharge and NO23 are less sensitive, and TSSX and PO4X more sensitive, to changes in intra-monthly rainfall variability. The largest increases may result from constituents moved by detached sediment in heavy rainfall events.

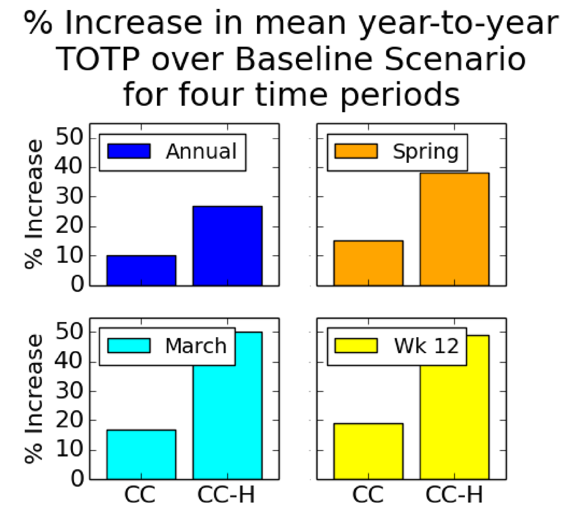


* All results are annual averages for each ten year simulation. Q=discharge, TSSX=total suspended solids, TSED=total sediment, TOTP=total phosphorus, PO4X=phosphates, ORGP=organic phosphorus, TOTN=total nitrogen, ORGN=organic nitrogen, and NO23=nitrite and nitrate.

II The upper right figure shows that a 1% increase in the extreme rainfall multiplier produced an approximate 0.1% / 0.6% / 1.5% increase in total N/P/SS respectively, with greater marginal change at higher multipliers.



III The lower right figure shows that the CC-H scenario increases relative loading of TOTP more than the CC scenario at different times of year. Changes in the timing of intra-annual delivery could have important effects on the estuary ecology [7].



* Note results from the bottom figure were obtained from simulation of the Upper Patuxent Watershed only.

Conclusions

- We developed a novel algorithm to simulate an increase in extreme rainfall variability while keeping mean monthly precipitation constant.
- Our results suggest that increasing intra-monthly rainfall variability is more likely to cause an increase in P and SS, and less likely to affect Q and N. The change may be more pronounced during certain periods of the year.
- Through this and future work we hope to identify general characteristics of the landscape that indicate sensitivity to changes in rainfall variability.

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References:
[1] Melilo, J., Richmond, T. C. & Yohe, Gary, E. Climate Change Impacts in the United States: The Third National Climate Assessment. 841 (2014). doi:10.7930/J0Z31WJ2.
[2] Pyke, C. R. et al. Climate Change and the Chesapeake Bay: State-of-the-Science Review and Recommendations. A Report from the Chesapeake Bay Program Science and Technical Advisory Committee (STAC). Annapolis, MD 59, (2008).
[3] Herrmann, M. & Najjar, R. Climate-Change Forcing Function. in Chesapeake Bay Model. Quarterly. Review Meeting Annapolis,, (2013).
[4] USEPA. Chesapeake Bay Phase 5.3 Community Watershed Model. EPA 903S10002 - CBP/TRS-303-10. (2010). at <http://ches.communitymodeling.org/models/CBPhase5/documentation.php>
[5] Hay, L., Markstrom, S. & Ward-Garrison, C. Watershed-Scale Response to Climate Change through the Twenty-First Century for Selected Basins across the United States. Earth Interact. (2011).
[6] Program for Climate Model Diagnosis and Intercomparison. BCCR-BCM2.0. (2005). at <http://www-pcmdi.llnl.gov/ipcc/model_documentation/BCCR_BCM2.0.htm>
[7] Najjar, R. G. et al. Potential climate-change impacts on the Chesapeake Bay. Estuar. Coast. Shelf Sci. 86, 1–20 (2010).