How will the impact of climate change on riverine nutrient loading impact Chesapeake Bay hypoxia?

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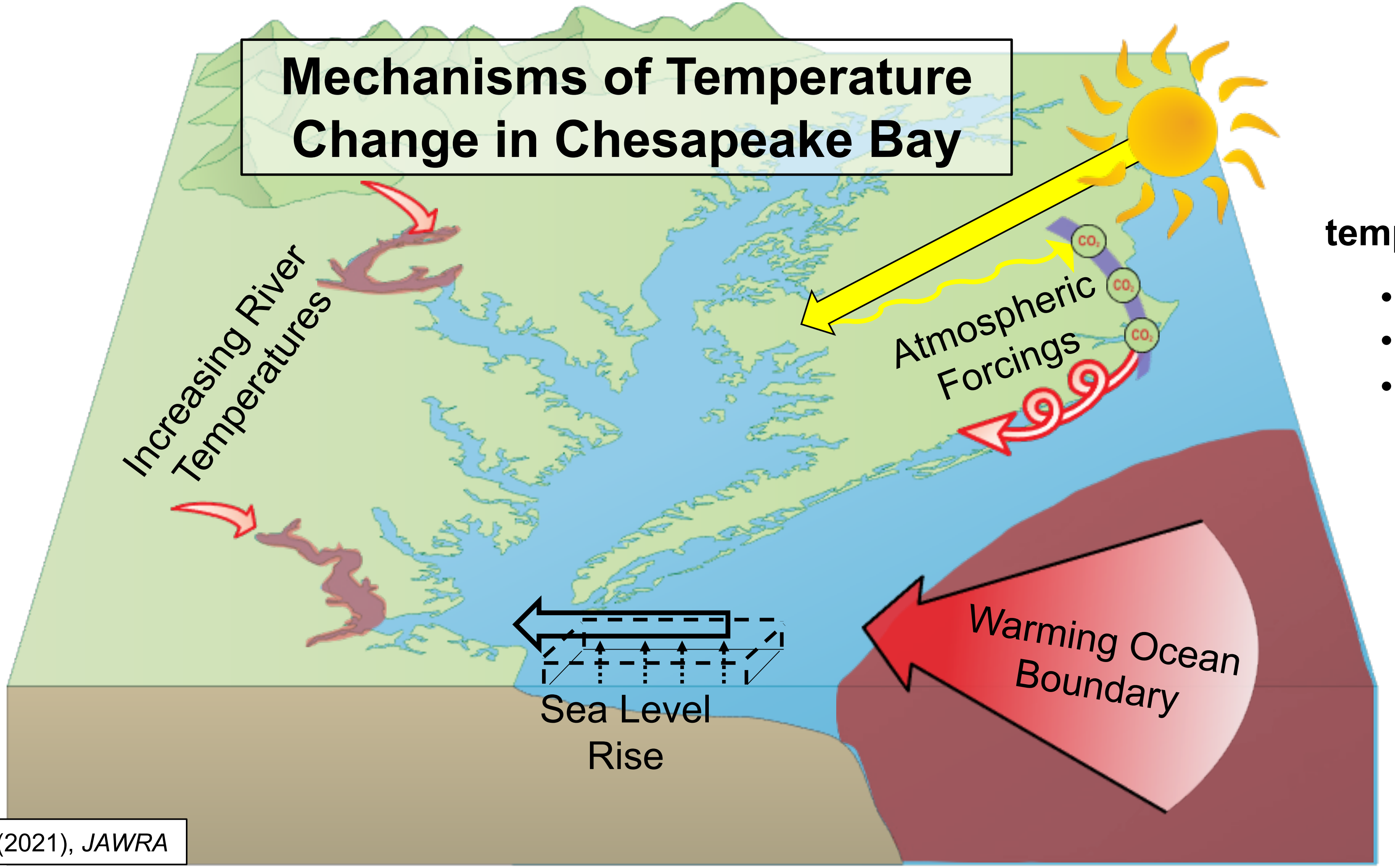
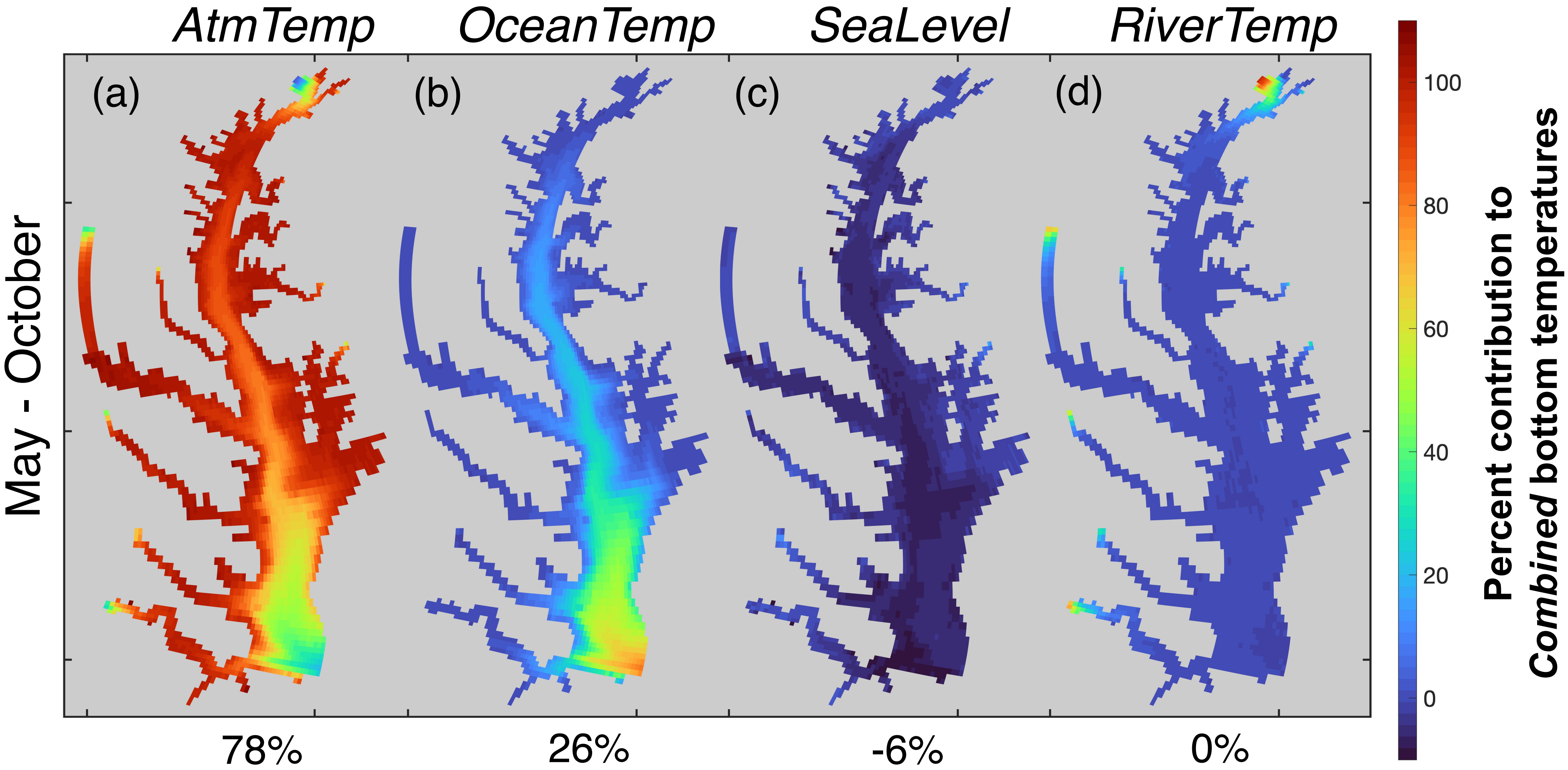
What is driving Chesapeake Bay warming?



Hinson et al. (2021), *JAWRA*

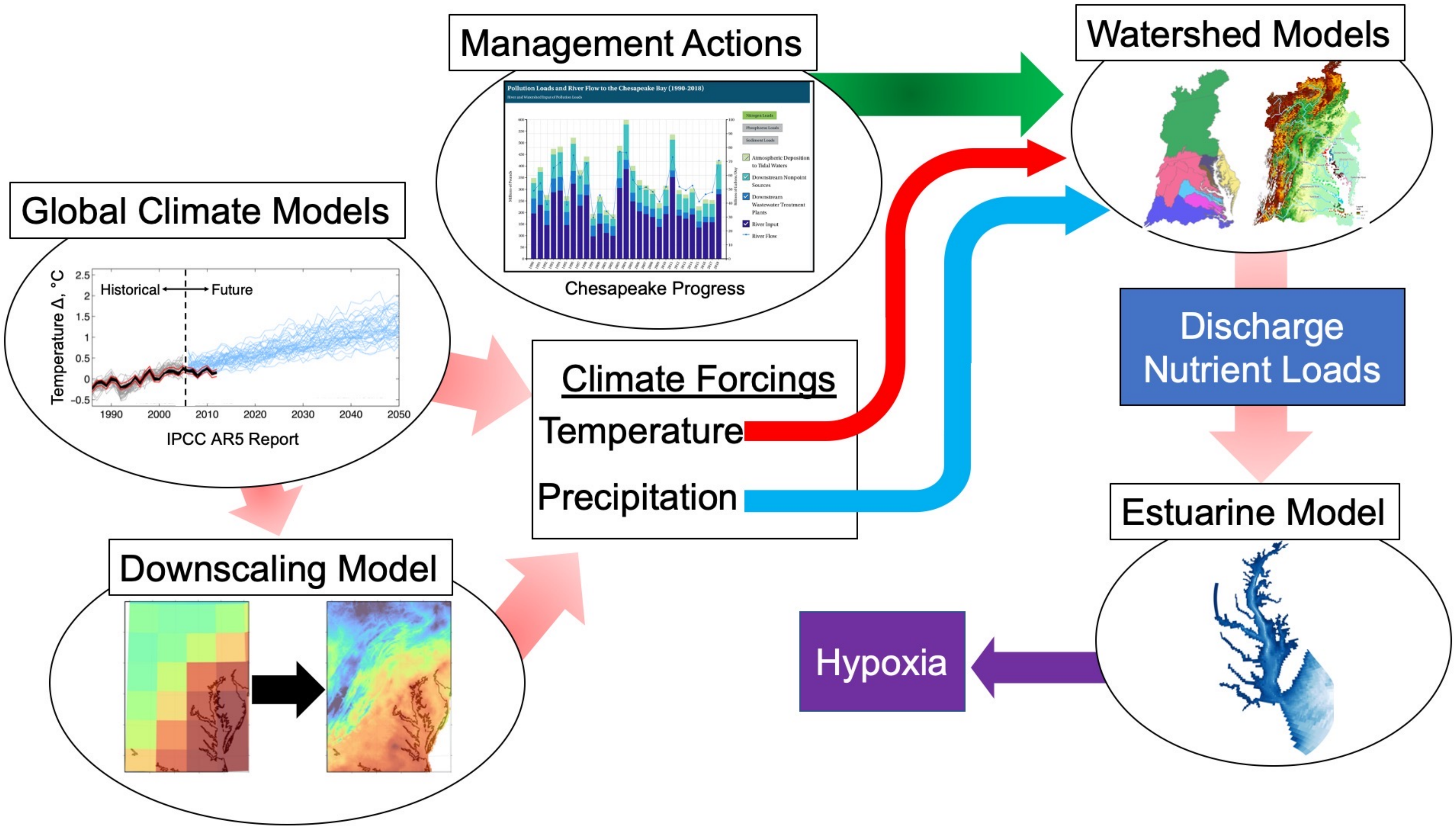
From 1985-2019 temperatures increased by:

- 0.02°C y^{-1} annually
- 0.04 °C y^{-1} May-Oct
- 0.01 °C y^{-1} Nov-Apr

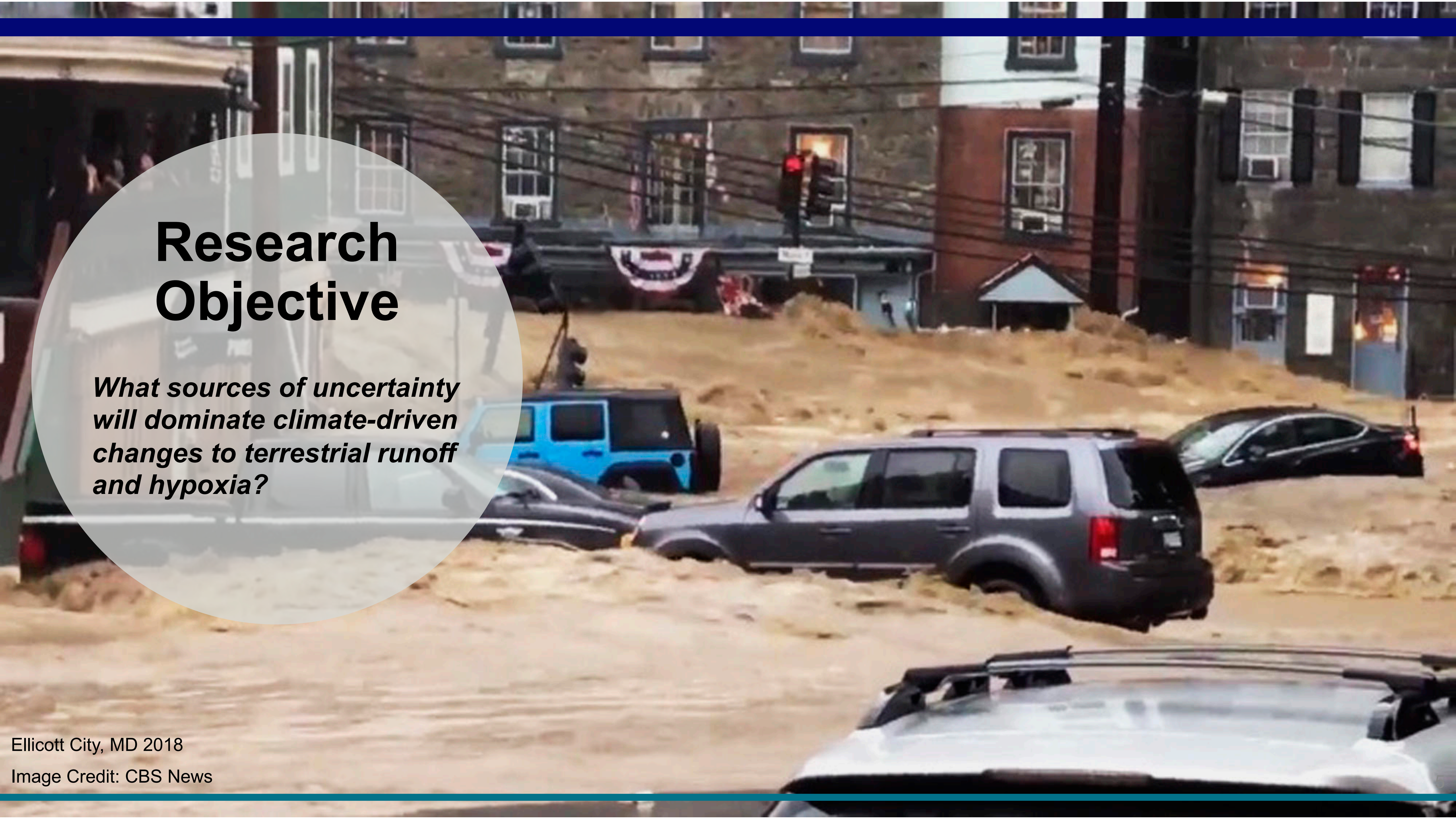


- Atmospheric warming dominates almost everywhere
- Ocean warming plays large role in southern Bay
- Rivers important to heads of tributaries, SLR slightly cools everywhere

Hinson et al. (2021), *JAWRA*



Numerous sources of uncertainty in climate projections should be considered:
Global Climate Model, Downscaling Model, Watershed Model, and Management Actions.



Research Objective

What sources of uncertainty will dominate climate-driven changes to terrestrial runoff and hypoxia?

Ellicott City, MD 2018

Image Credit: CBS News

ChesROMS-ECB Overview

Atmospheric Forcings

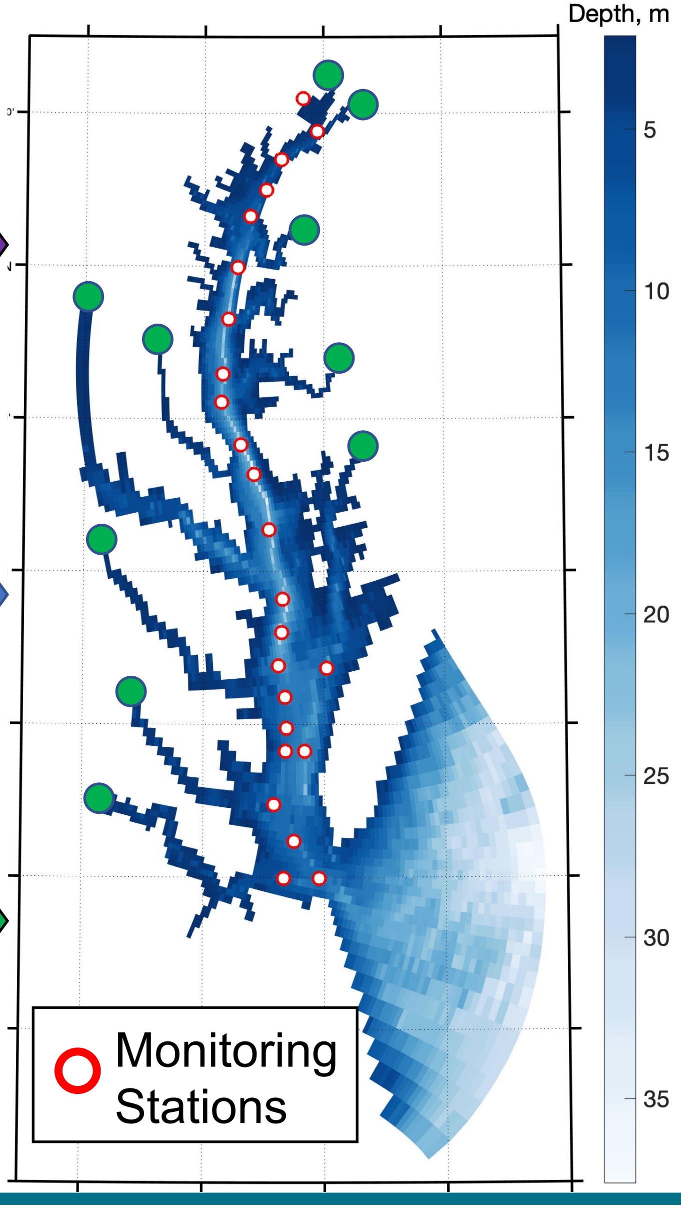
→ Hindcast weather data

Coastal Fluxes

→ Climatological data

Riverine Inputs

→ DLEM Watershed Model
→ Phase 6 Watershed Model



Model Information

3-D model, 20 depth levels
Daily outputs
Base Scenario: 1991-2000
Climate Scenarios: 2050

Model Outputs

Hydrodynamics and Biogeochemistry

ChesROMS-ECB Overview

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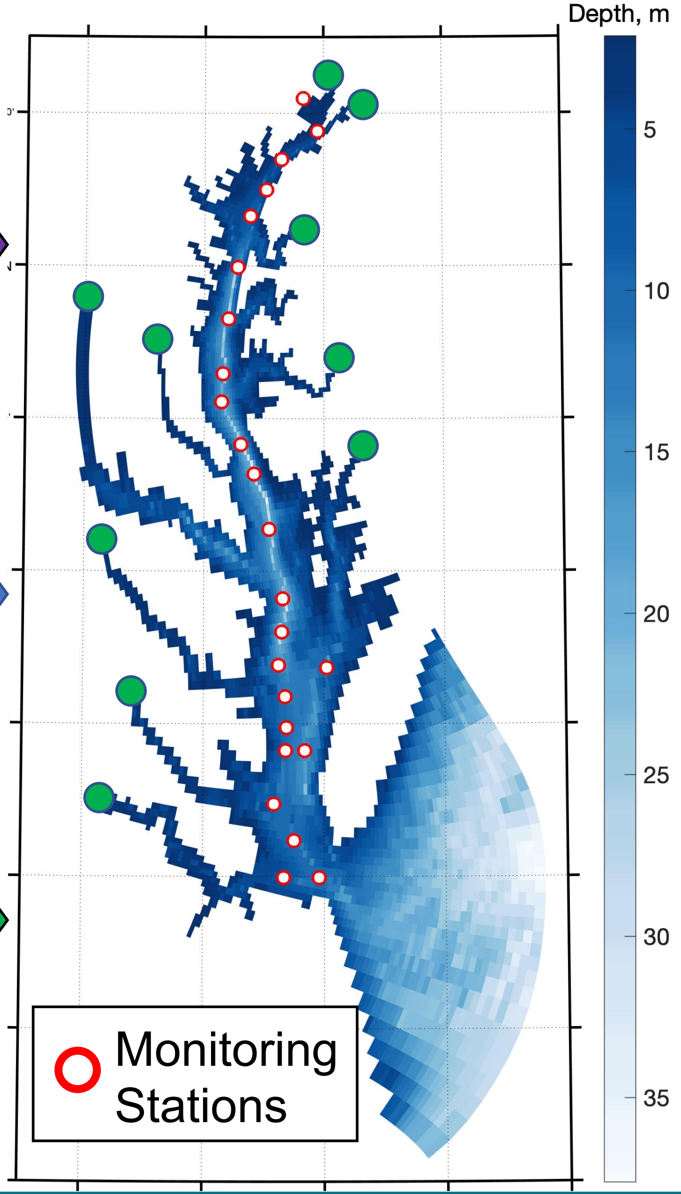


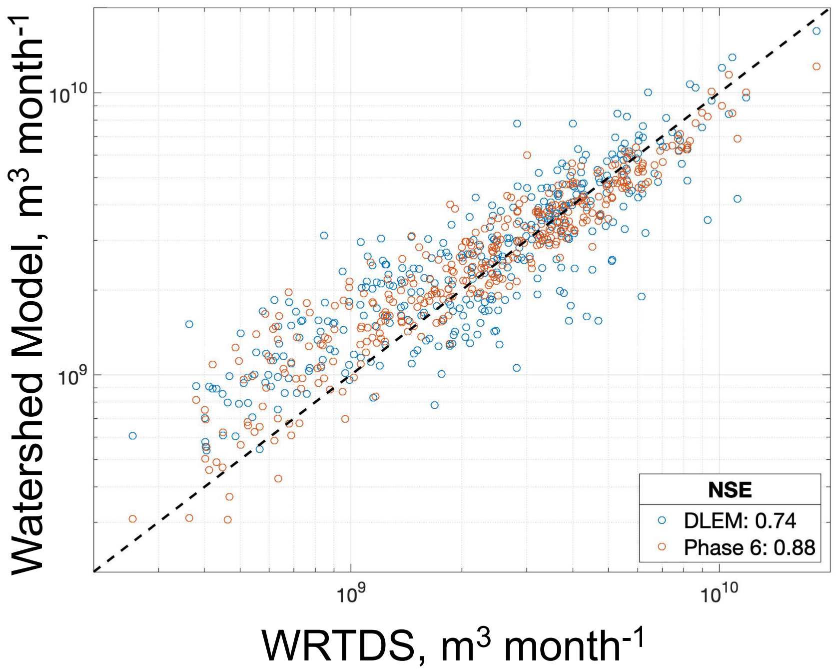
Model Information
3-D model, 20 depth levels Daily outputs Base Scenario: 1991-2000 Climate Scenarios: 2050

Model Outputs

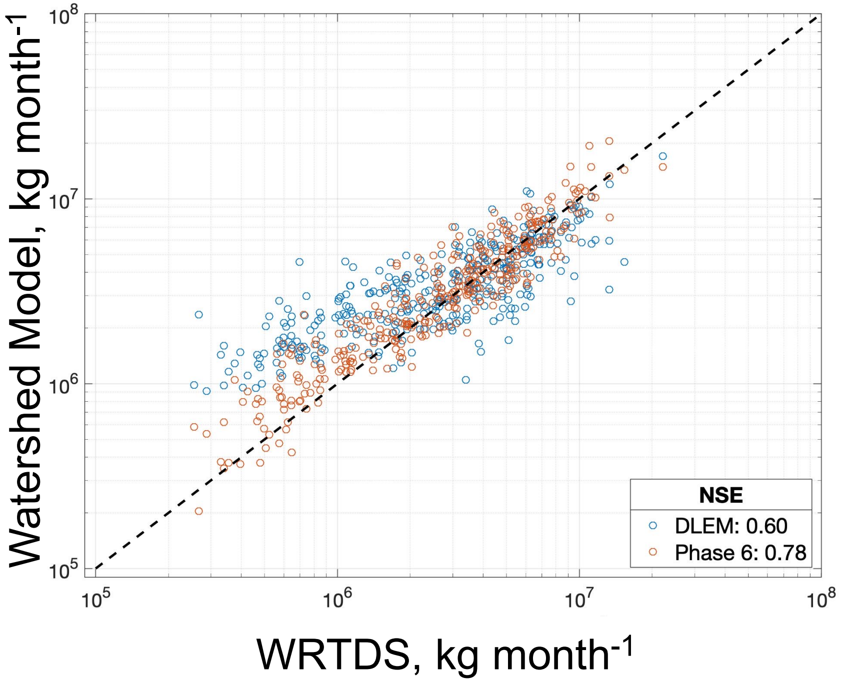
Hydrodynamics and Biogeochemistry

WRTDS vs Watershed Model Comparisons - Susquehanna

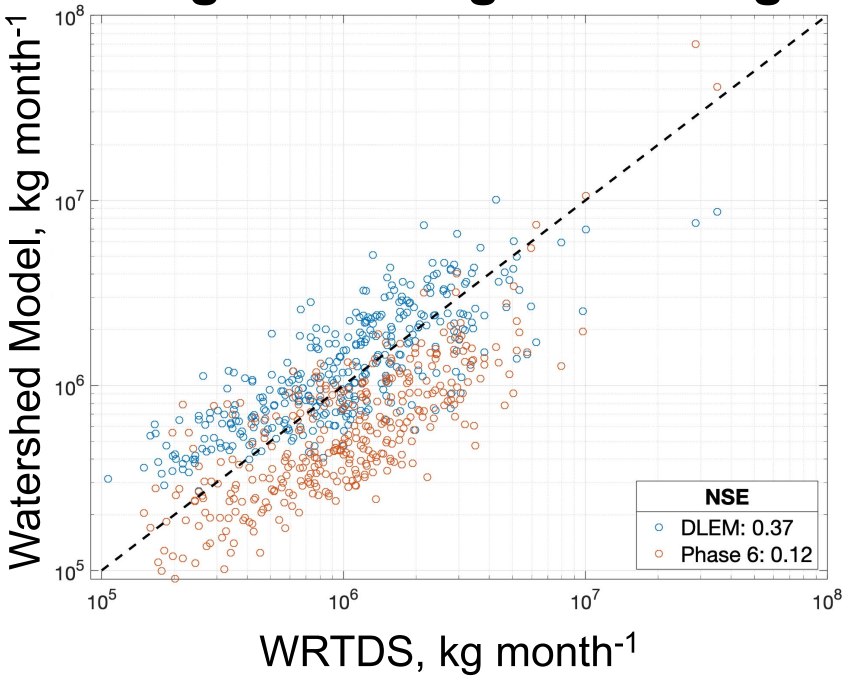
Discharge



Nitrate Loading



Organic Nitrogen Loading

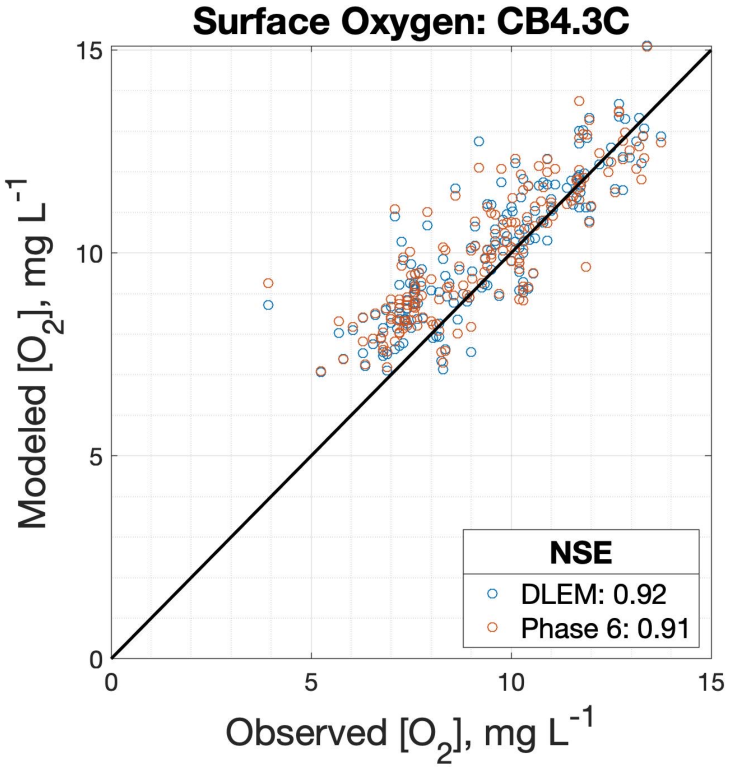


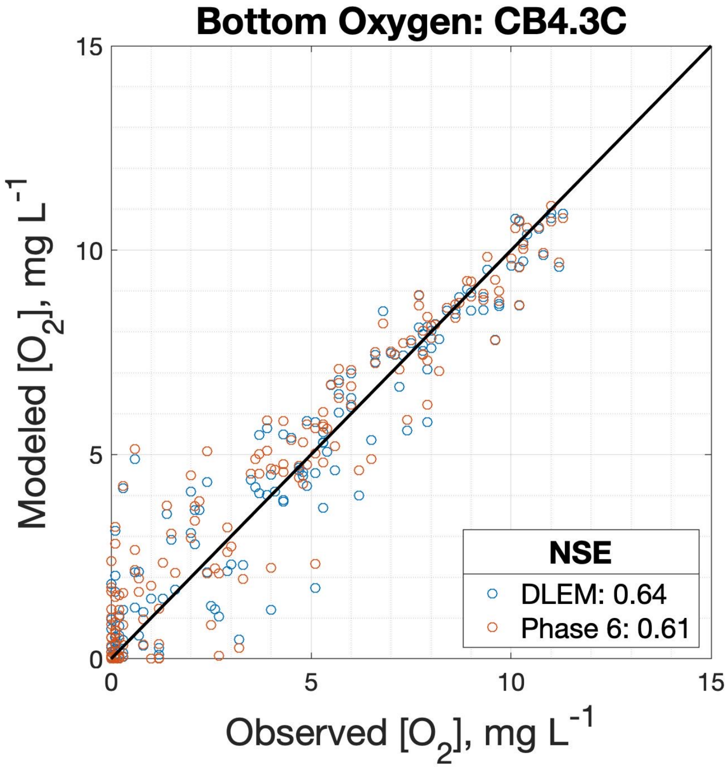
- Comparison of DLEM and Phase 6 watershed models against WRTDS estimates from 1991-2000.
- Modeled estimates and skill of discharge are approximately equal.
- Phase 6 produces more nitrate loading than DLEM and more closely matches WRTDS.
- DLEM produces more organic nitrogen loading and more closely matches WRTDS.

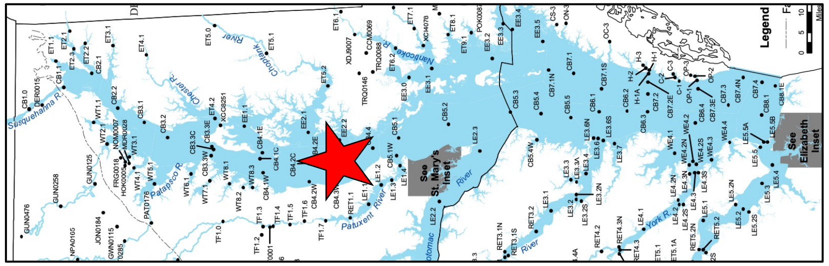
→ *Overall, both models produce similar estimates of skill for total nitrogen loading.*

Bay Oxygen Estimates

- Past evaluations of long-term $[O_2]$ by Pierre St-Laurent have shown comparable skill for both WSMs.
- At central Chesapeake Bay Station, there is identical skill for both WSMs.
- Despite differences in WSM nitrogen species loading, results are consistent with each other.





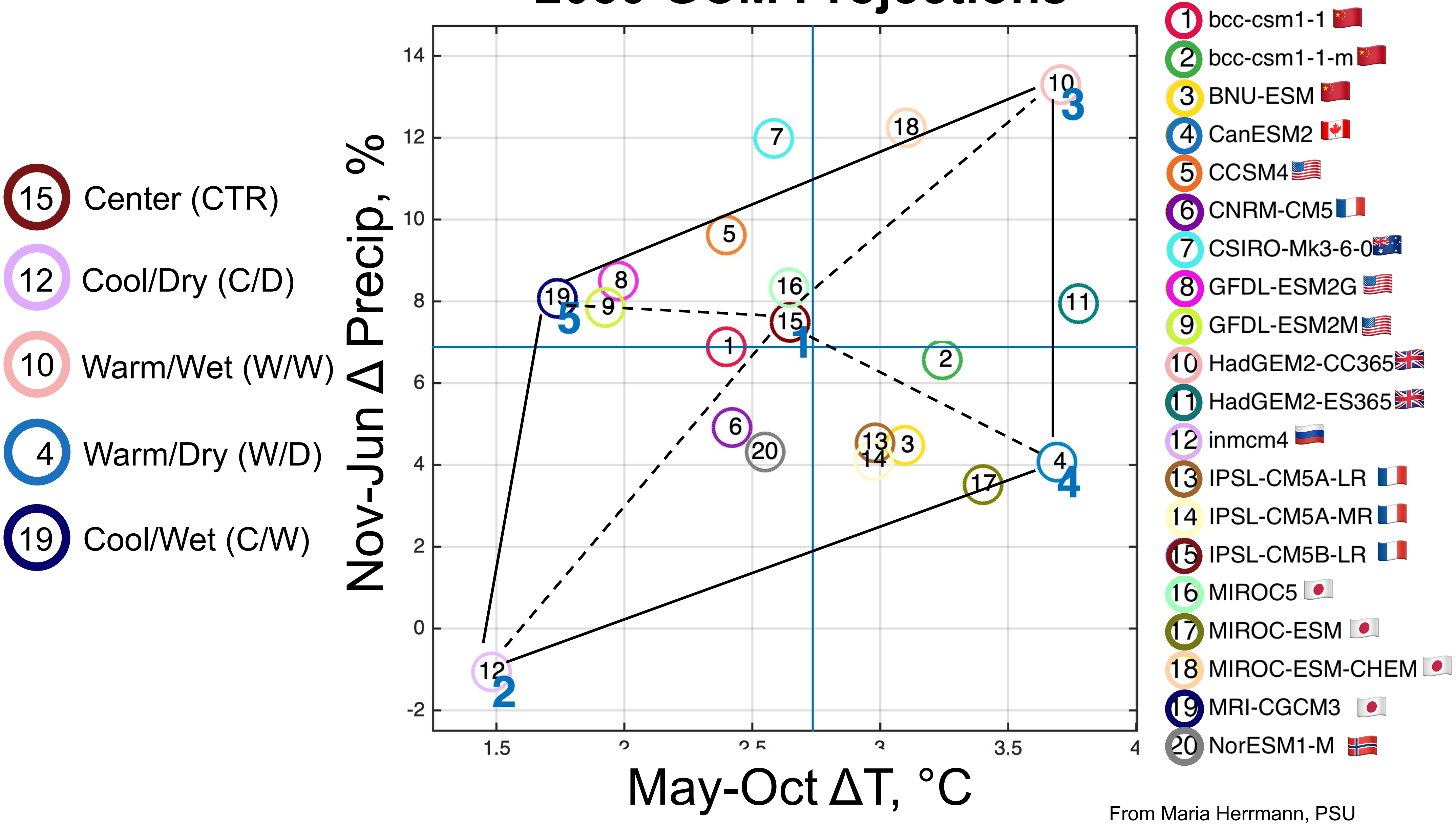


Climate Scenarios – WSM Comparisons

- Applied 5 GCMs to each experiment to compare sources of uncertainty.
- Also included a median model for Phase 6 estimates.
- Total of 23 climate scenarios centered around 2050.

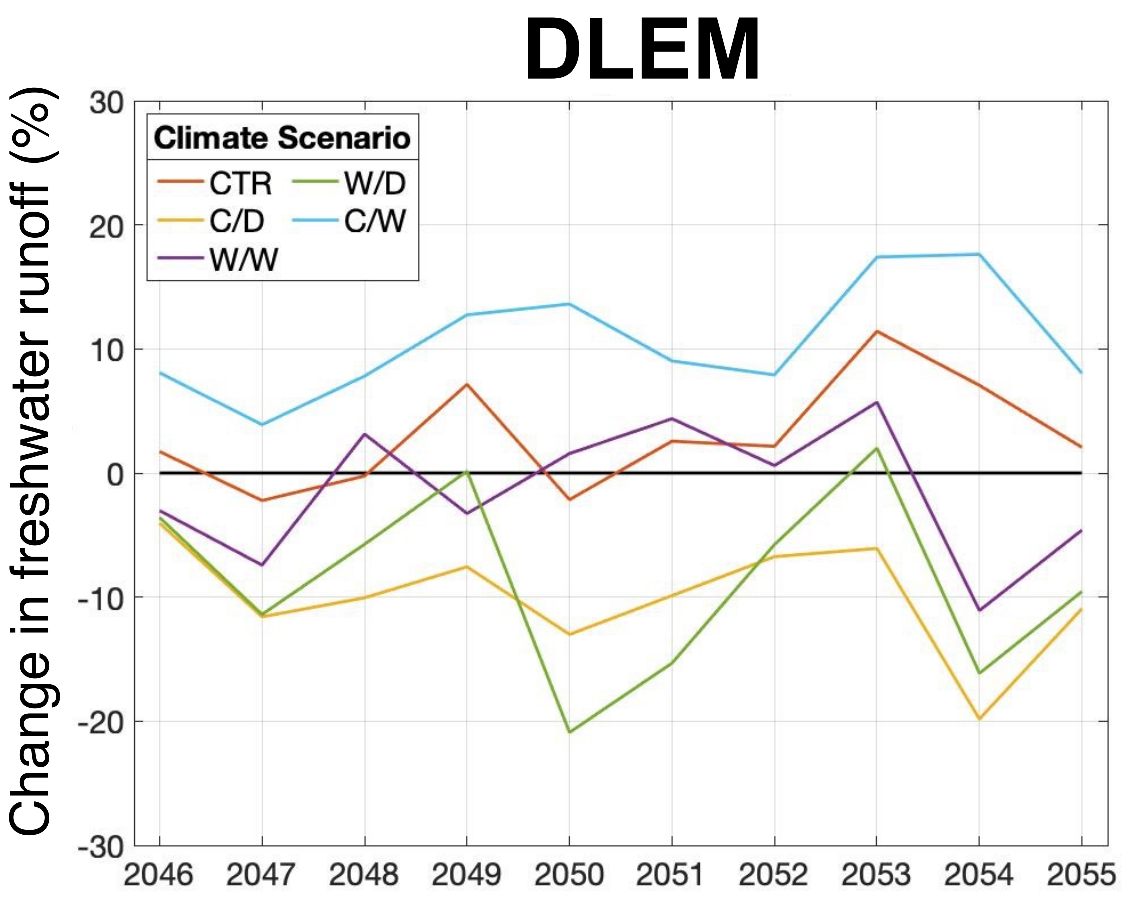
Uncertainty Metric	Management Conditions	Downscaling Model	Watershed Model
Expt. 1 GCM	1990s	MACA	P6 WSM
Expt. 2 Management	TMDL	MACA	P6 WSM
Expt. 3 Downscaling	1990s	BCSD	P6 WSM
Expt. 4 Watershed Model	1990s	MACA	DLEM

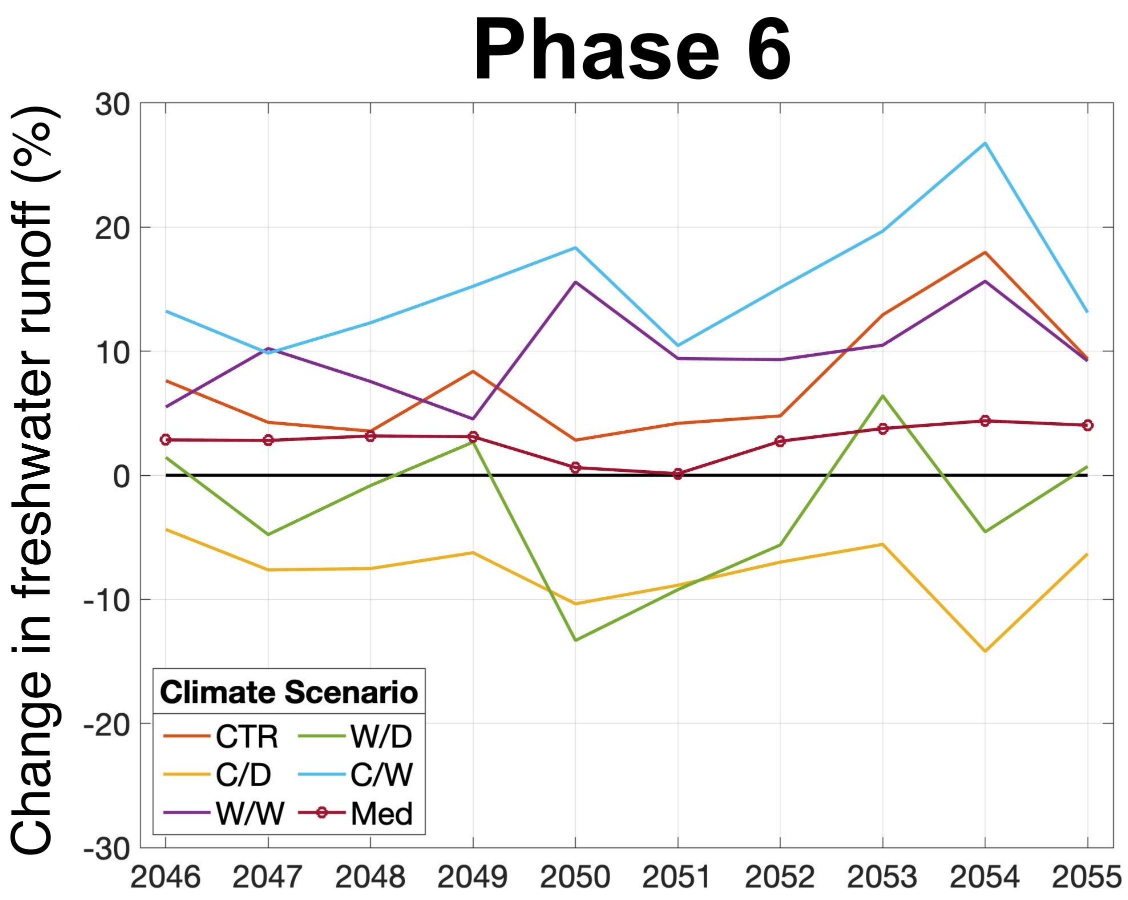
2050 GCM Projections



From Maria Herrmann, PSU

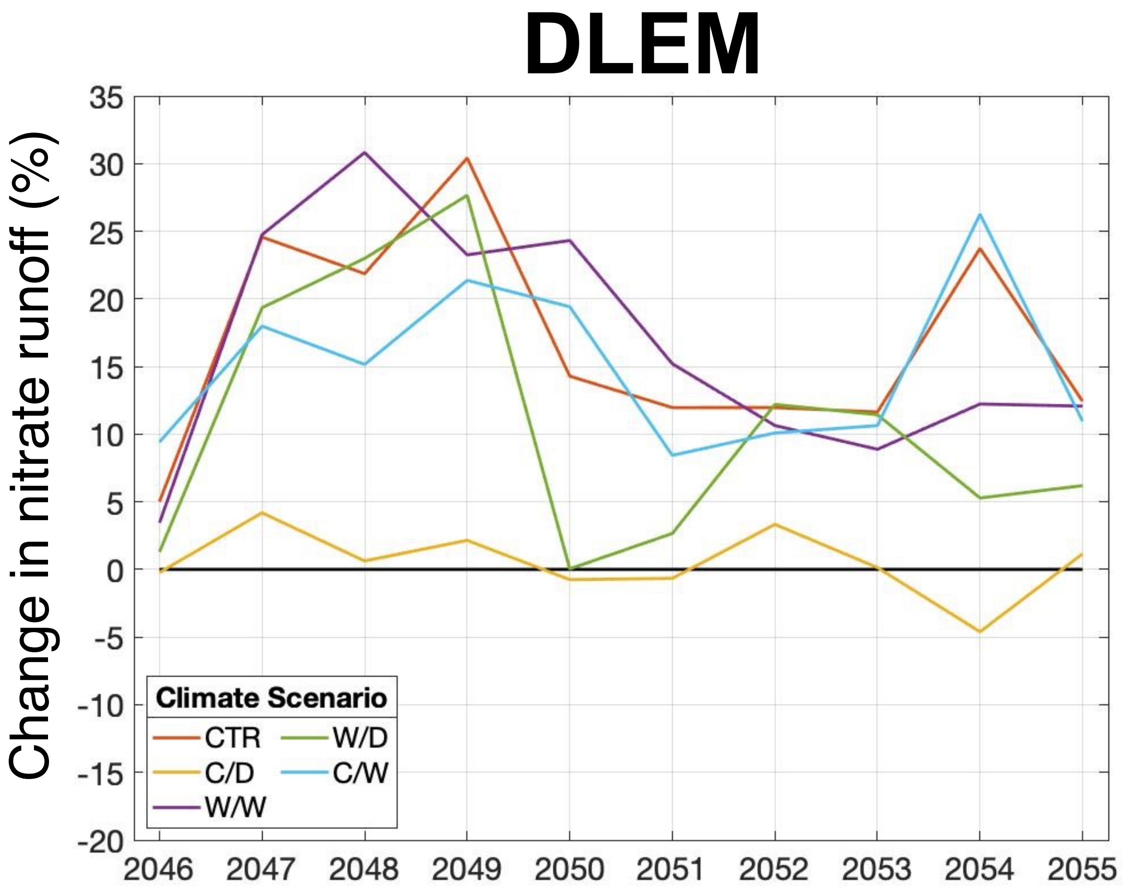
Watershed Impacts: Discharge

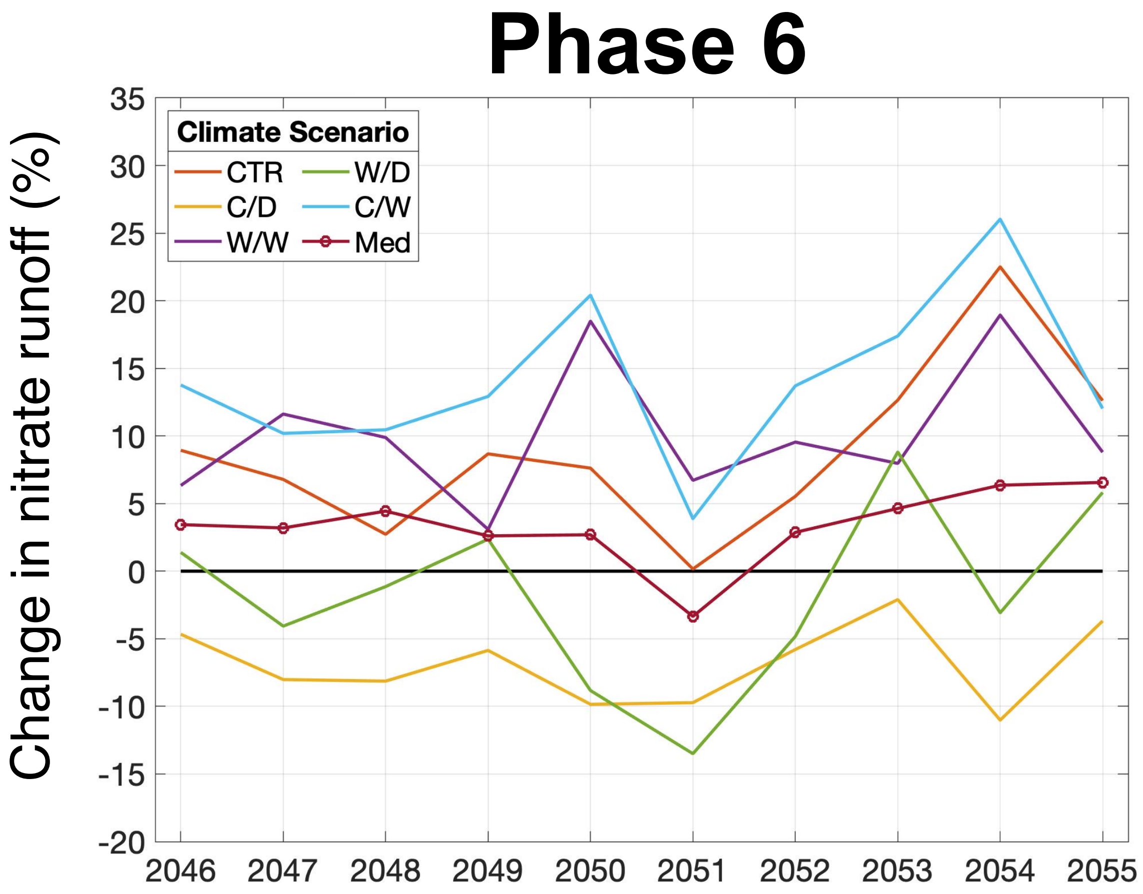




- GCM choice is very important to river discharge, but watershed models show similar results.

Watershed Impacts: Nitrate

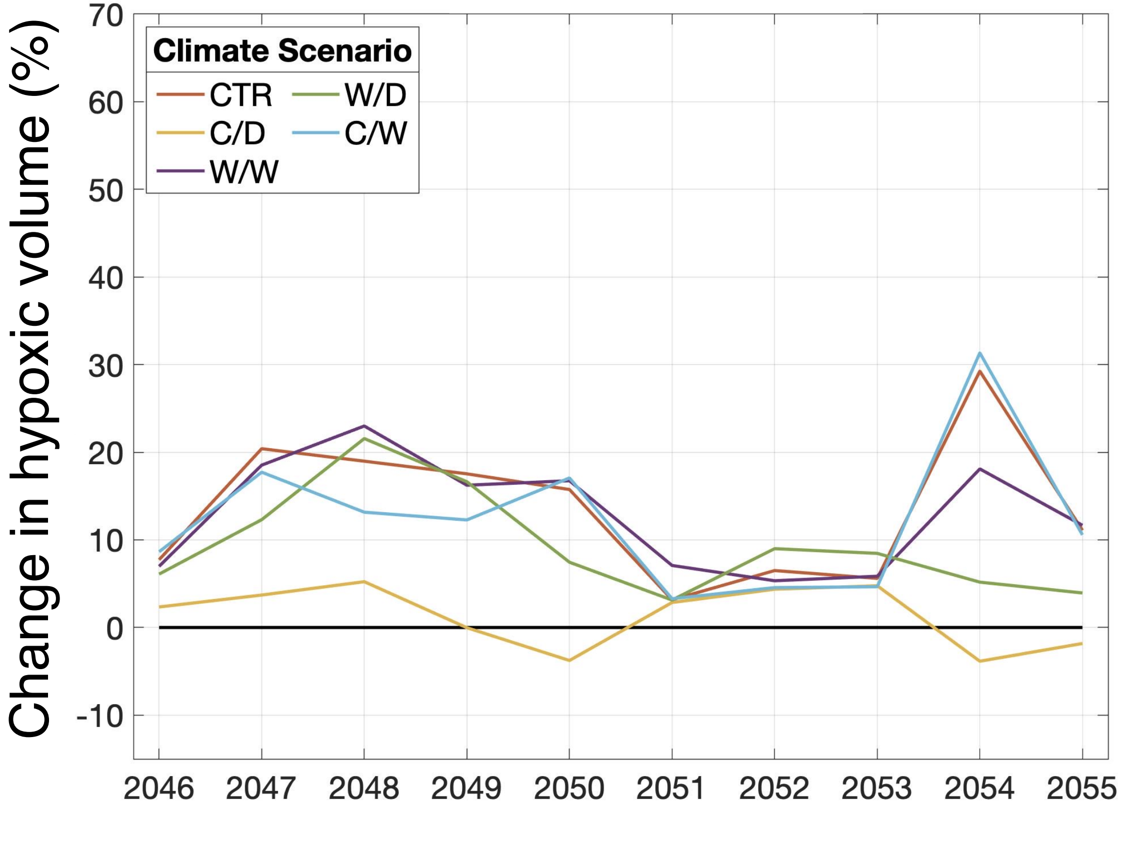




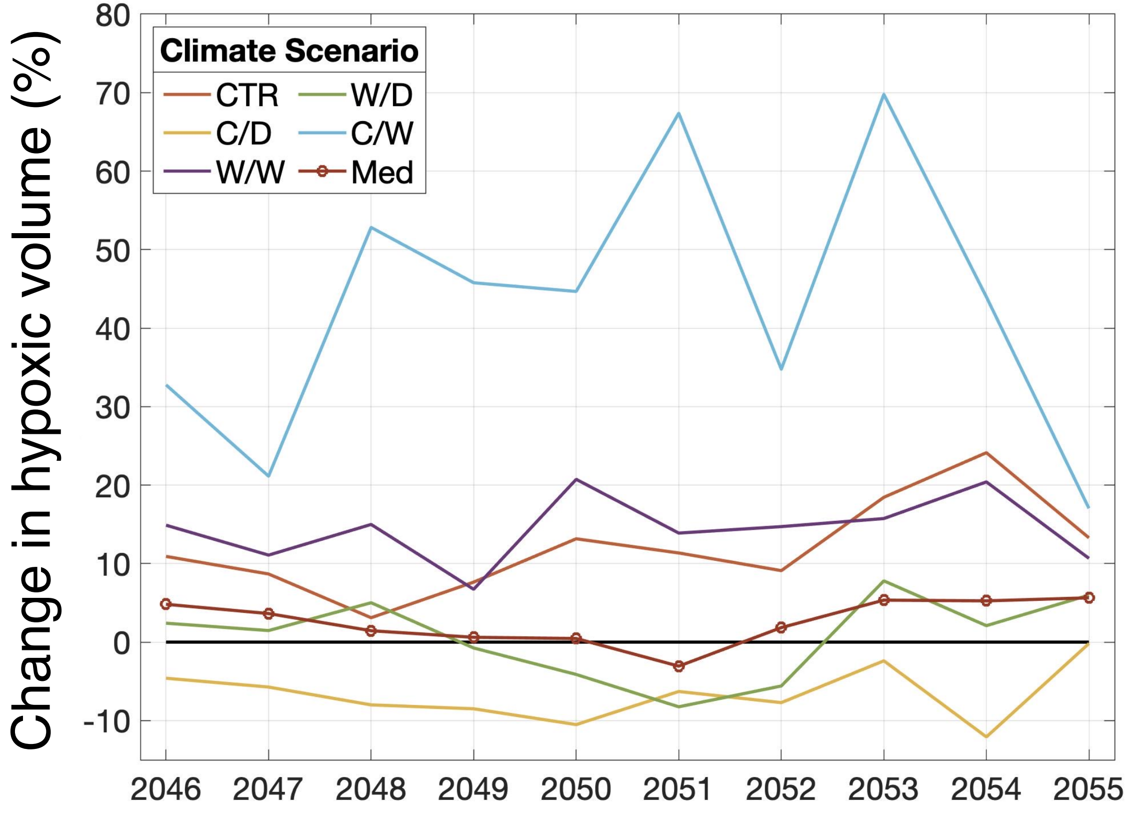
- Differences among GCMs ≥ differences between watershed models.

Estuary Impacts: Hypoxic Volume

DLEM



Phase 6



- Different GCMs result in similar estimates for DLEM, but Phase 6 estimates slightly more variable.

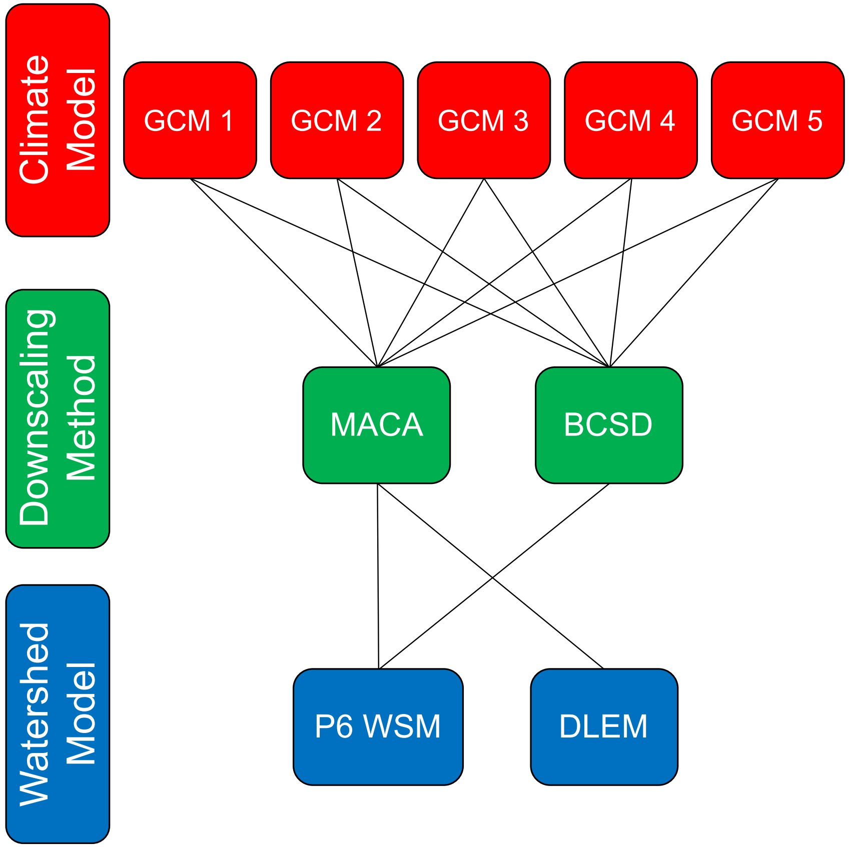
How to quantify uncertainty?

- ANOVA approach can provide information about uncertainty for multiple effects in climate scenarios.

$$SS_{total,GD} = \sum_{G=1}^{5}\sum_{D=1}^{2}\left(HV^{G,D} - HV^{\circ,\circ}\right)^{2}$$

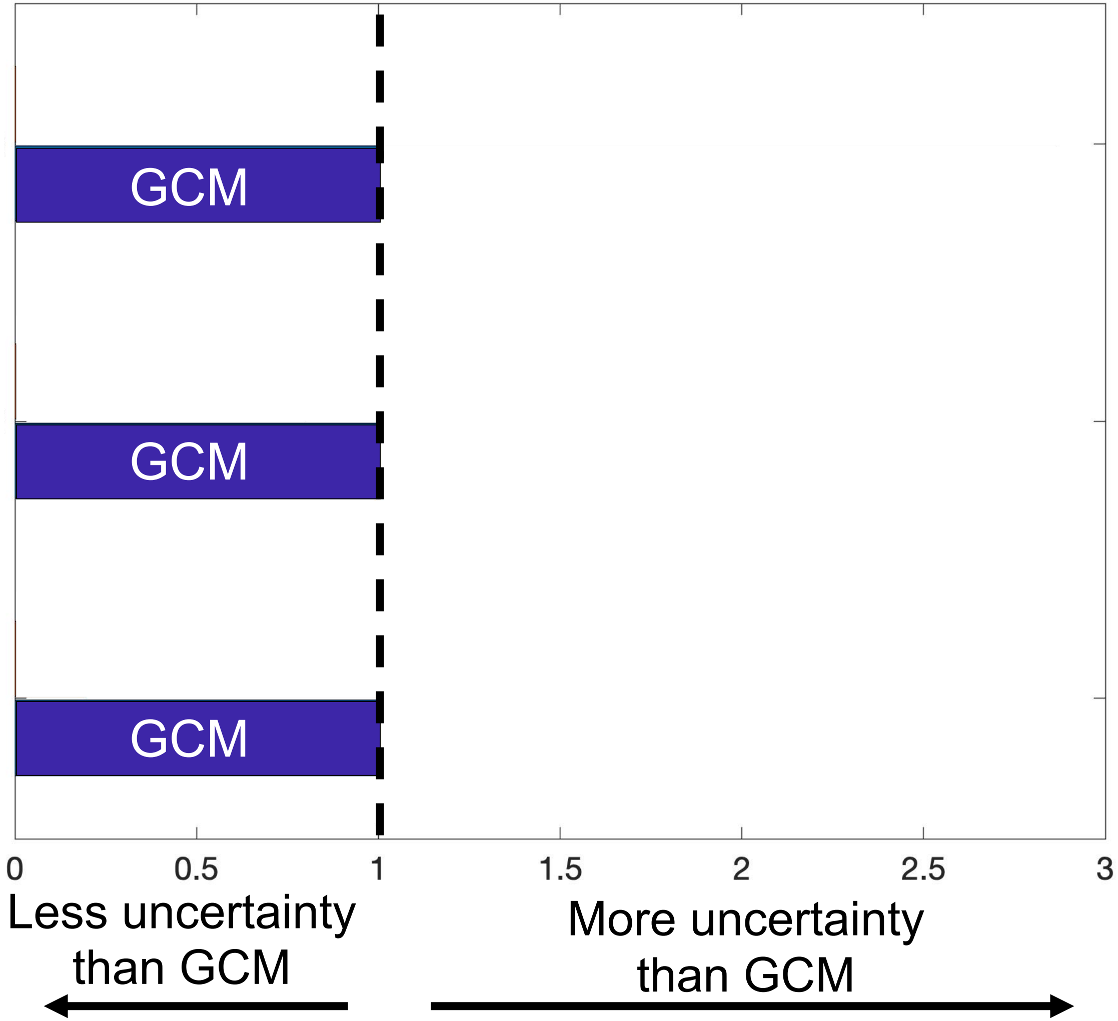
$$SS_{total,GH} = \sum_{G=1}^{5}\sum_{H=1}^{2}\left(HV^{G,H} - HV^{\circ,\circ}\right)^{2}$$

Modified from:
von Storch and Zwiers, 1999
Bosshard et al., 2013, *Wat. Reso. Res.*



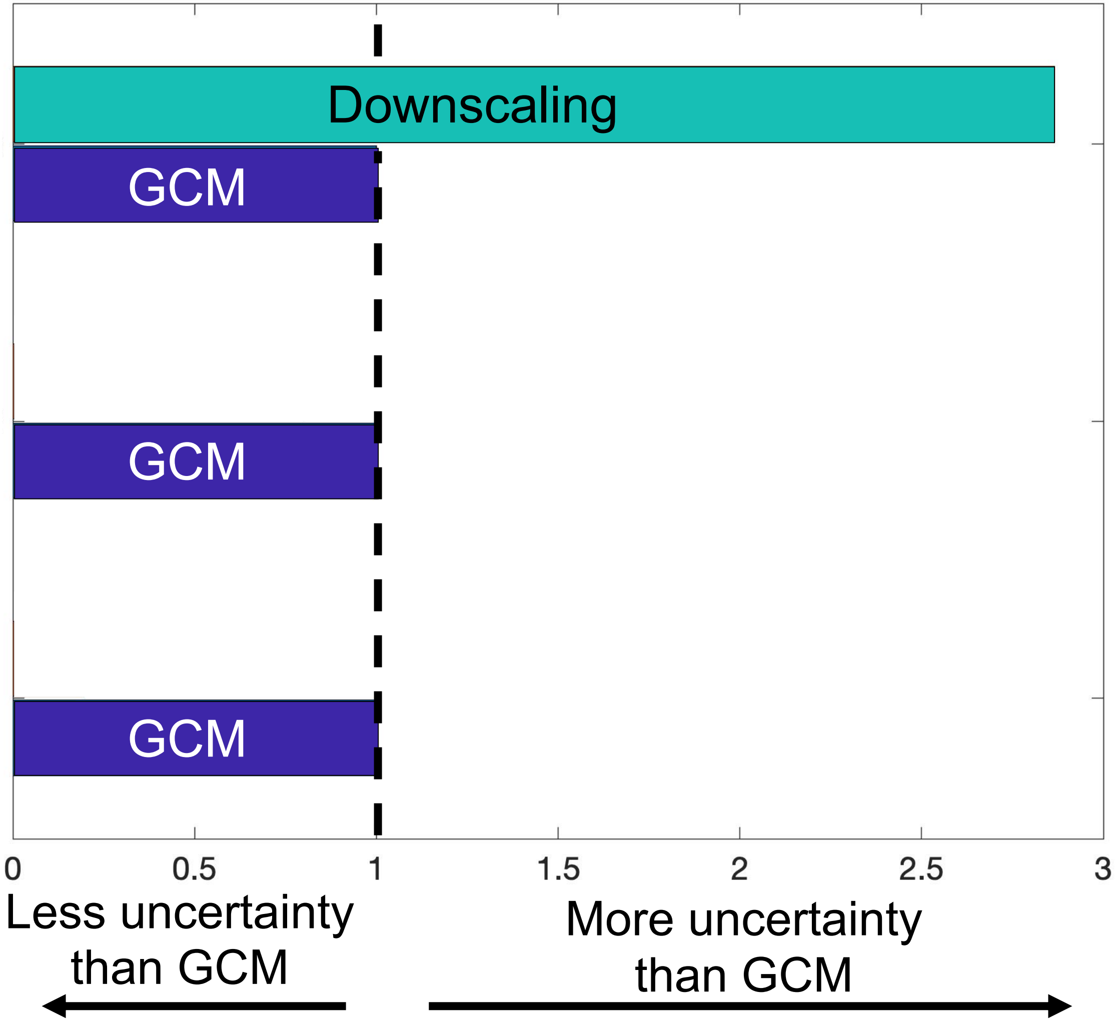
- Uncertainty defined here as fractional contribution of each effect to total.

Contribution to Uncertainty of Hypoxia Estimates



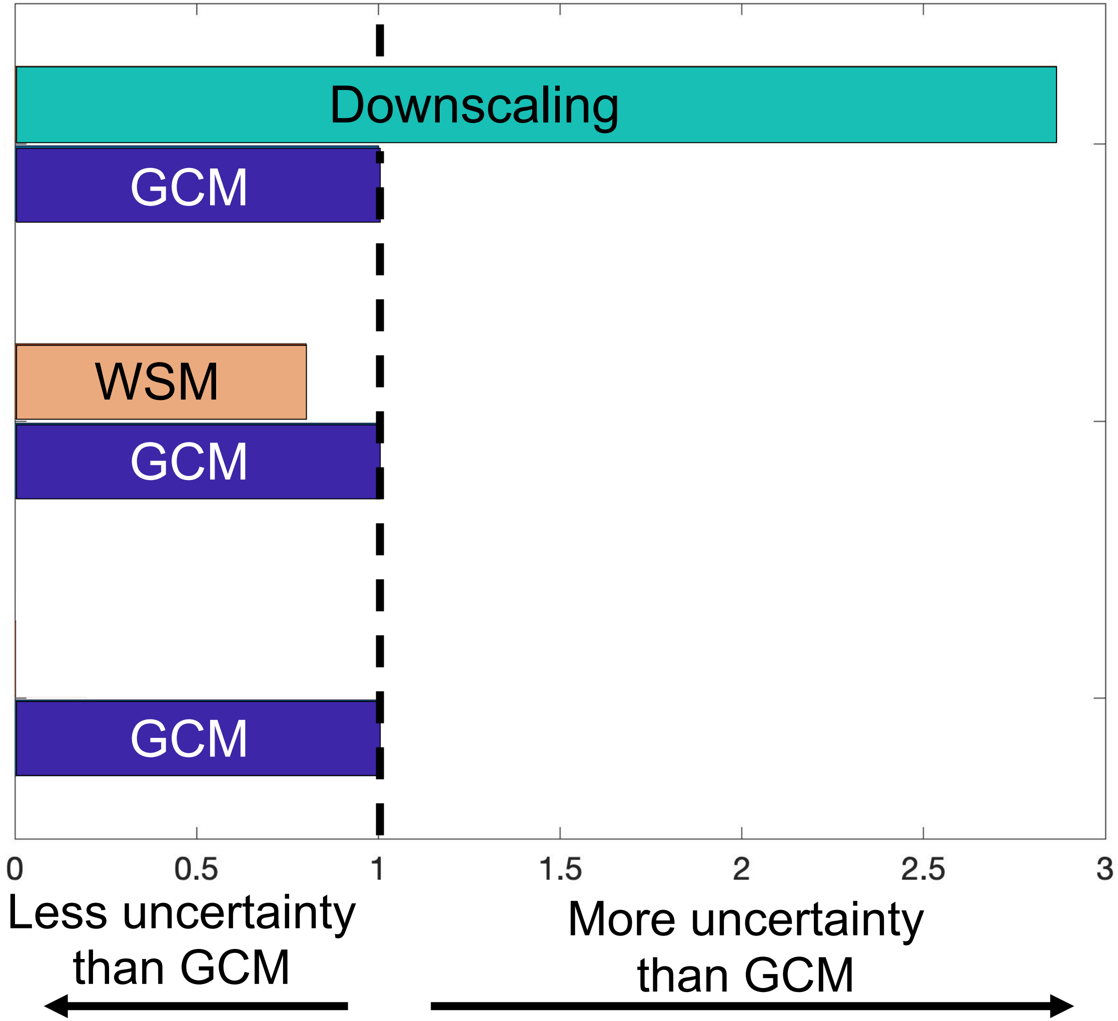
- Relative to the choice of GCM, how much uncertainty does downscaling introduce?

Contribution to Uncertainty of Hypoxia Estimates



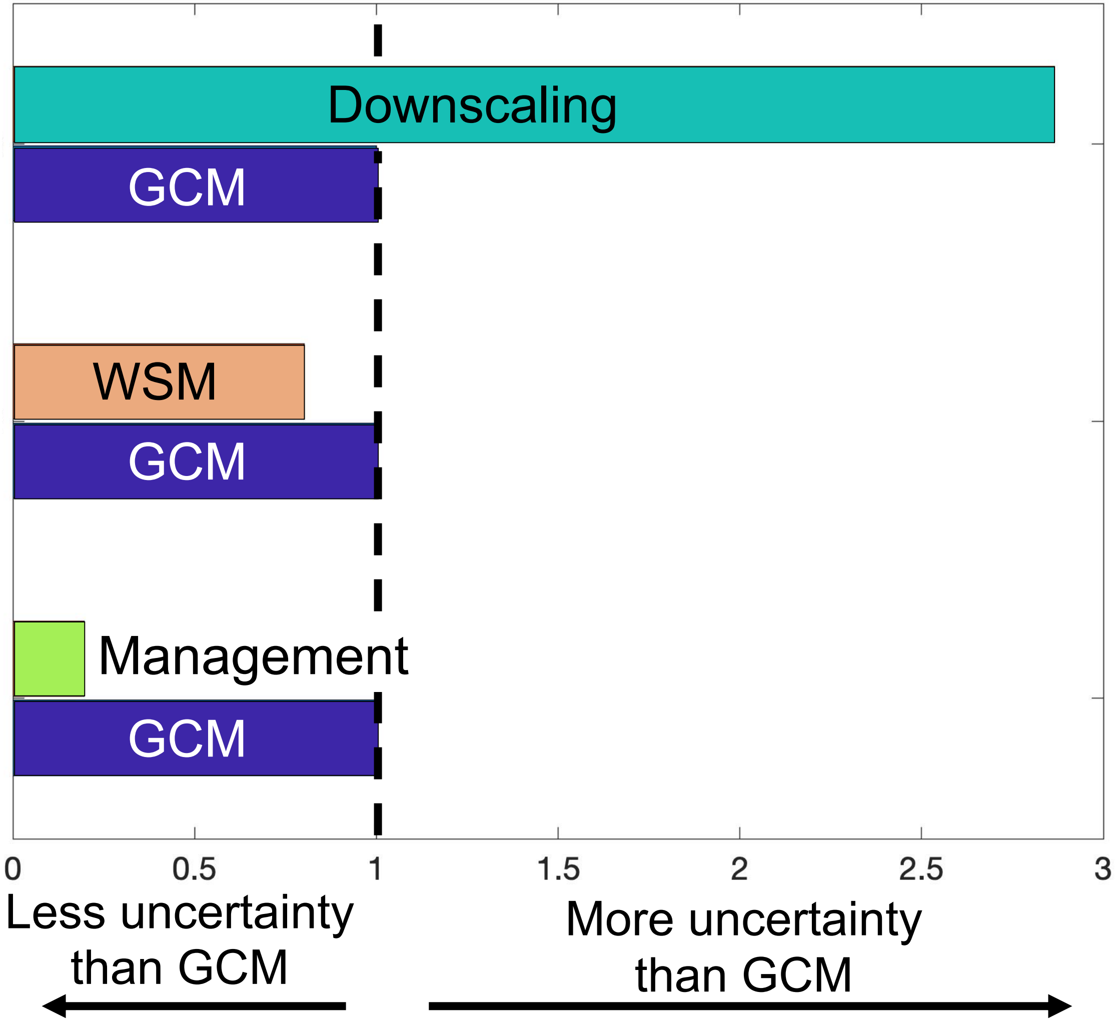
- Relative to the choice of GCM, how much uncertainty does downscaling introduce?
- Uncertainty due to downscaling is ~3x that due to GCM.

Contribution to Uncertainty of Hypoxia Estimates



- Relative to the choice of GCM, how much uncertainty does downscaling introduce?
- Uncertainty due to downscaling is ~3x that due to GCM
- Uncertainty due to GCM and Watershed Model (WSM) are approximately equal.

Contribution to Uncertainty of Hypoxia Estimates



- Relative to the choice of GCM, how much uncertainty does downscaling introduce?
- Uncertainty due to downscaling is ~3x that due to GCM
- Uncertainty due to GCM and Watershed Model (WSM) are approximately equal
- Effect of management produces least amount of uncertainty, but impacts hypoxia most.

Conclusions

- Assuming no changes in nutrient management, future terrestrial runoff will likely increase Bay hypoxia.
- Depending on the selection choices of GCM, downscaling model, and watershed model, future hypoxia estimates vary by 20-50%.
- Uncertainty in hypoxia outcomes due to:

  Downscaling Model > Global Climate Model

  Watershed Model ~ Global Climate Model

  Management Assumptions < Global Climate Model

Future Work

- Compare changes in other metrics (e.g., primary production, stratification, etc.)

- Assess probability of occurrence for changes in hypoxia, at different levels and in different regions