Comparison of Shallow-water Models for Use in Supporting Chesapeake Bay Management Decision-making

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Chesapeake Bay Program
A Watershed Partnership

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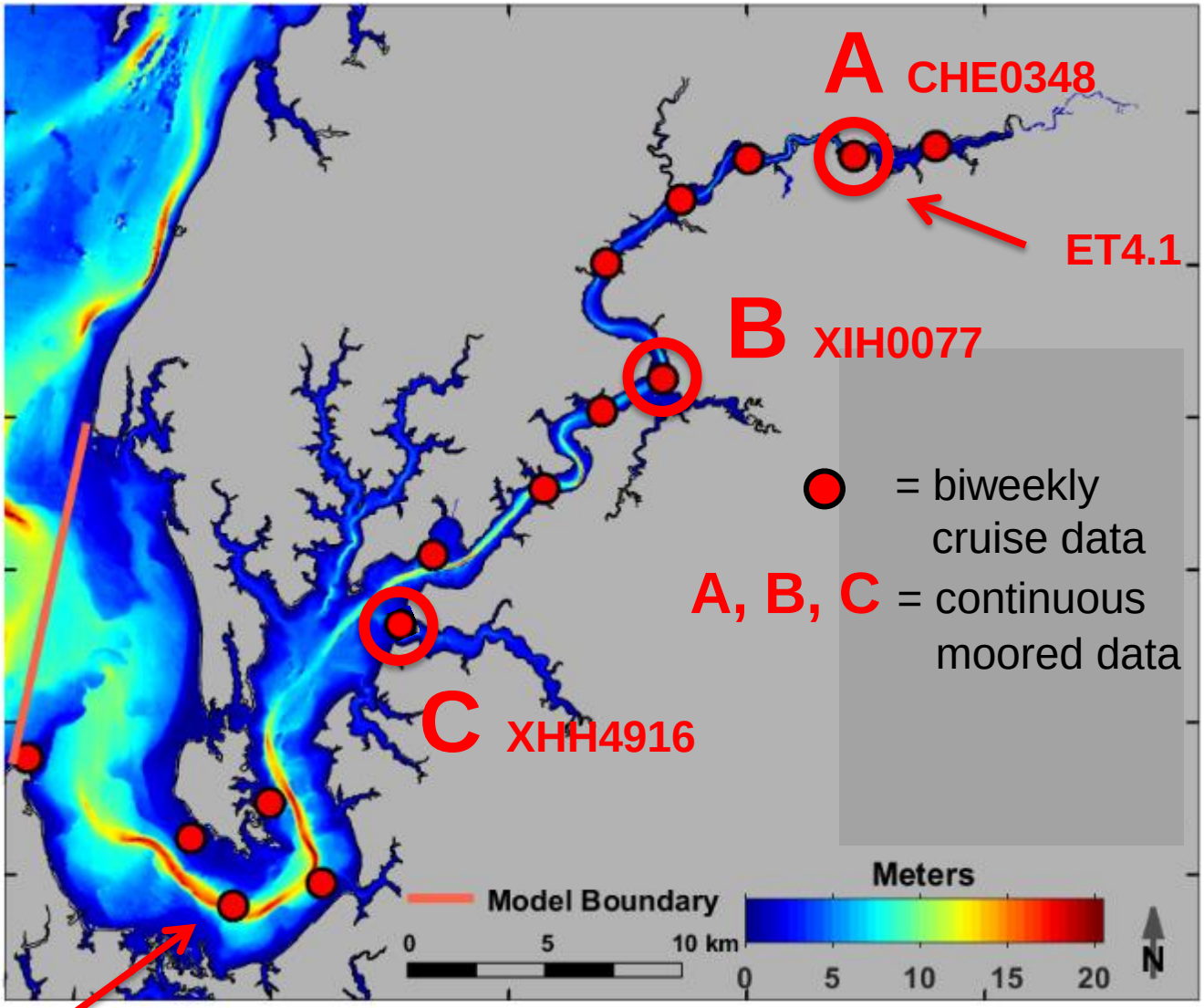
Outline

- **Study site: Chester River tributary**
  - Cruise and mooring data
- **Four participating models**
  - Similarities (forcing) and differences (grids)
- **Model performance for hydrodynamics (T, S)**
  - A. Base Case
  - B. Sensitivity experiments
  - Summary
- **Model performance for water quality (DO, chl, TSM)**
  - A. Base Case
  - B. Sensitivity experiments
  - Summary

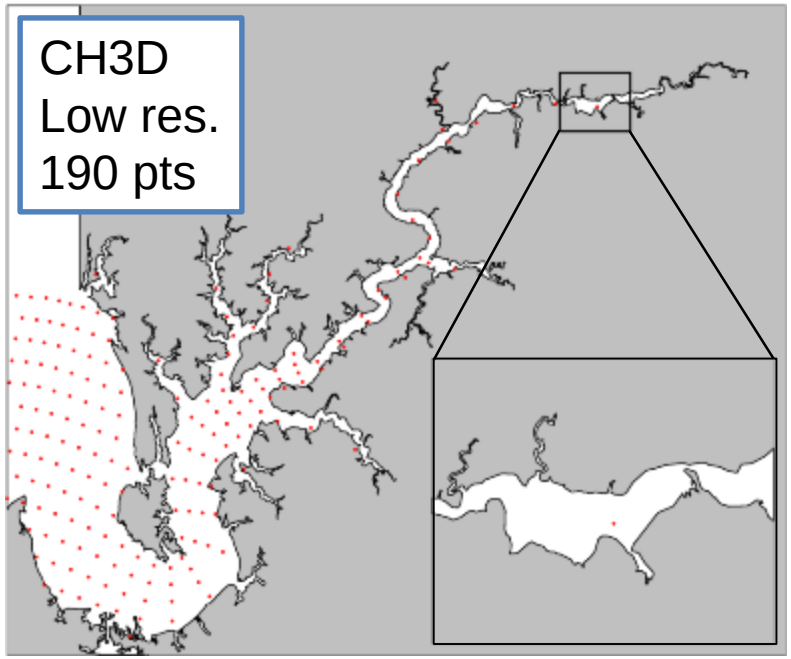
Observations: 2003-2006

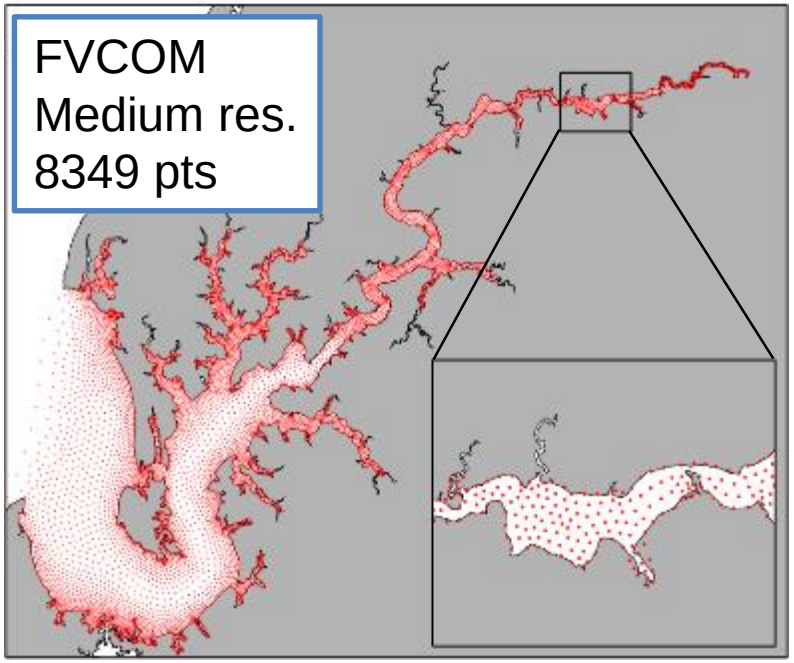


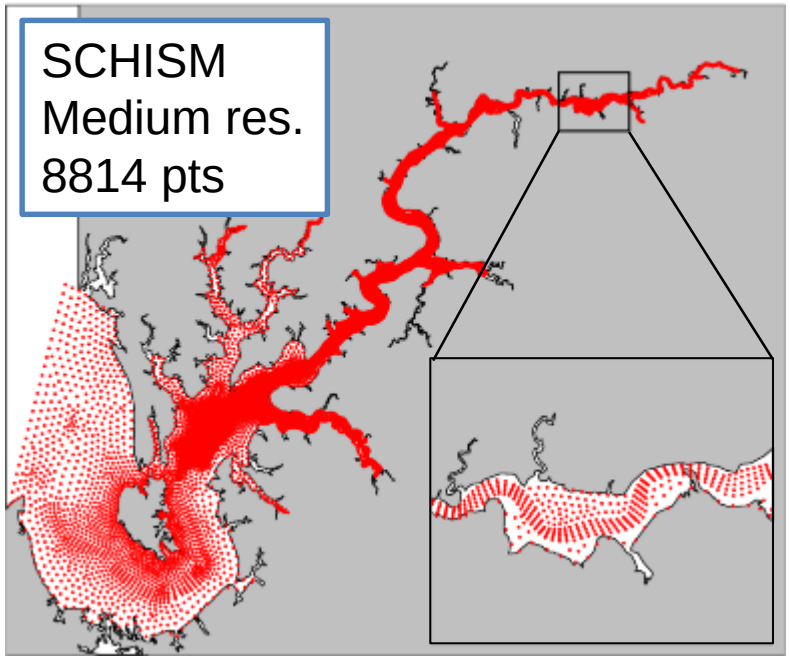
salinity, temperature, oxygen, chlorophyll, TSM

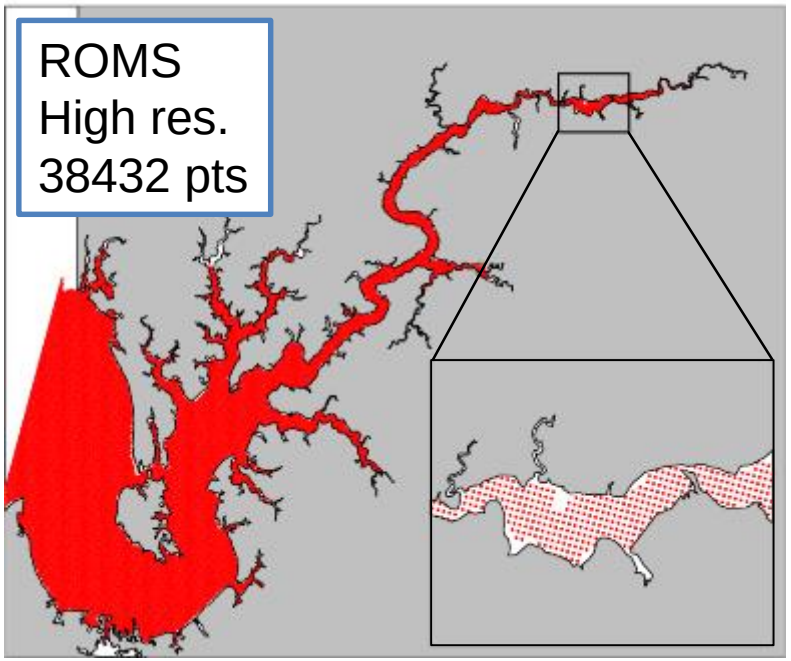
Participating models

Participating model	Horizontal resolution	Horizontal grid	Vertical grid
CH3D-ICM	**low**	structured	z-grid
FVCOM-ICM	medium	**triangular**	sigma
ROMS-RCA	**high**	structured	sigma
SCHISM-ICM	medium	**hybrid**	**hybrid**

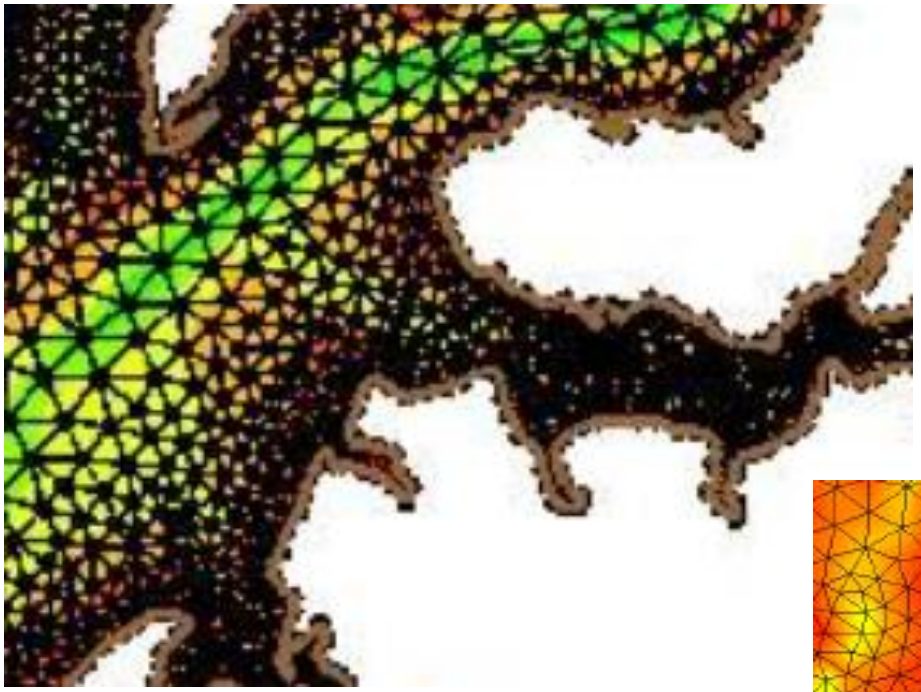

CH3D
Low res.
190 pts


FVCOM
Medium res.
8349 pts

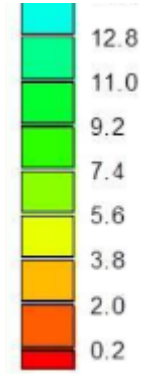

SCHISM
Medium res.
8814 pts


ROMS
High res.
38432 pts

FVCOM



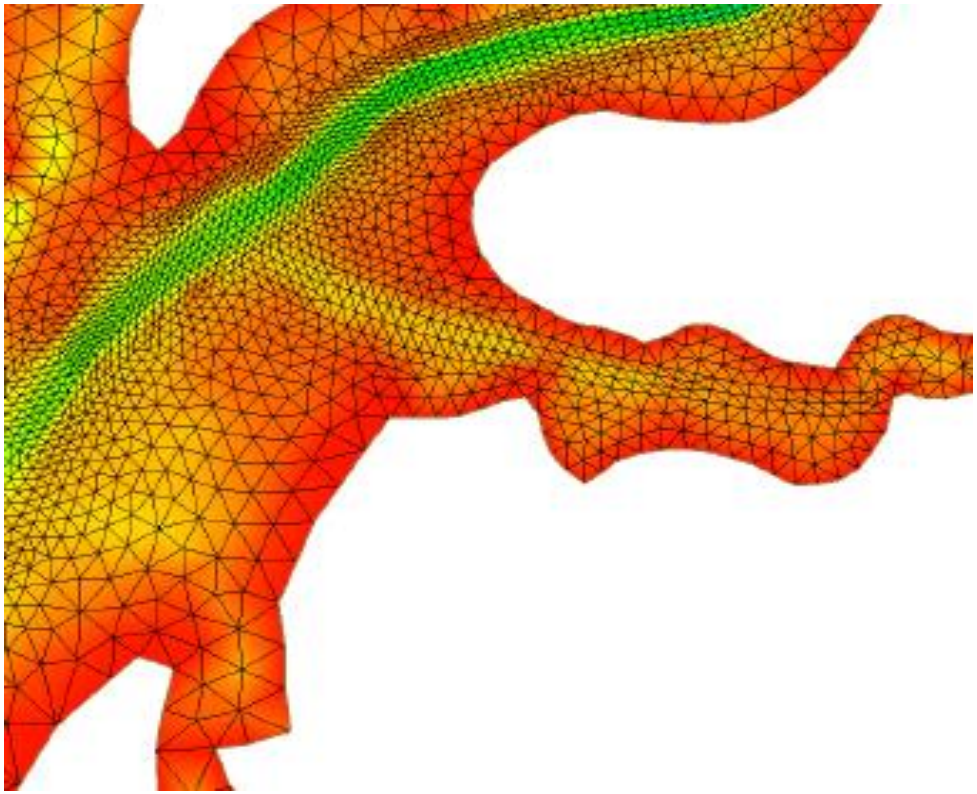
← FVCOM has a **low resolution grid in the trench**, with higher resolution on the flanks



Depth [m]

SCHISM has **a high resolution rectangular grid in the trench**, and lower resolution on the flanks →

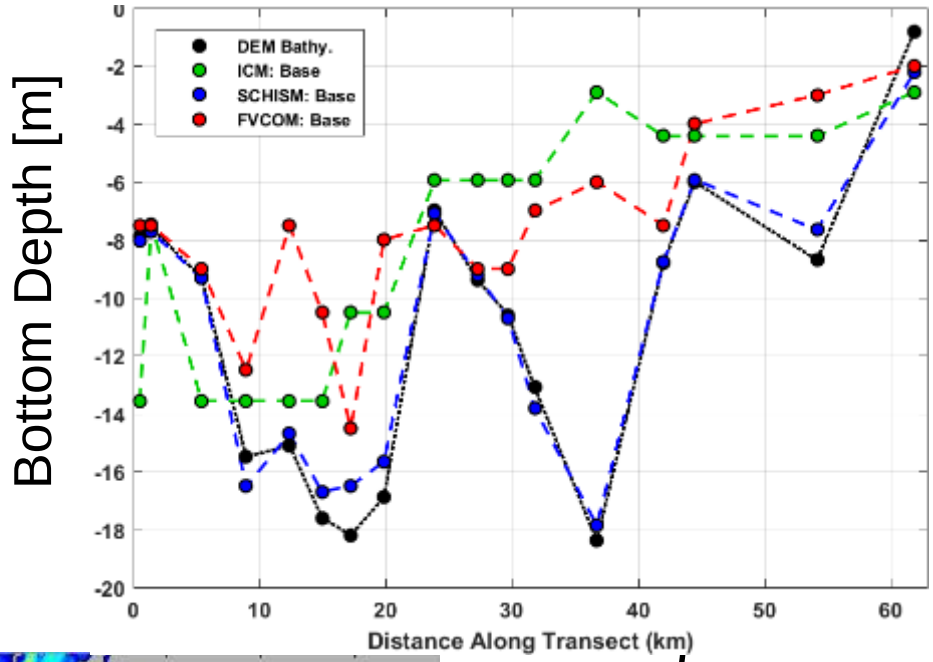
SCHISM

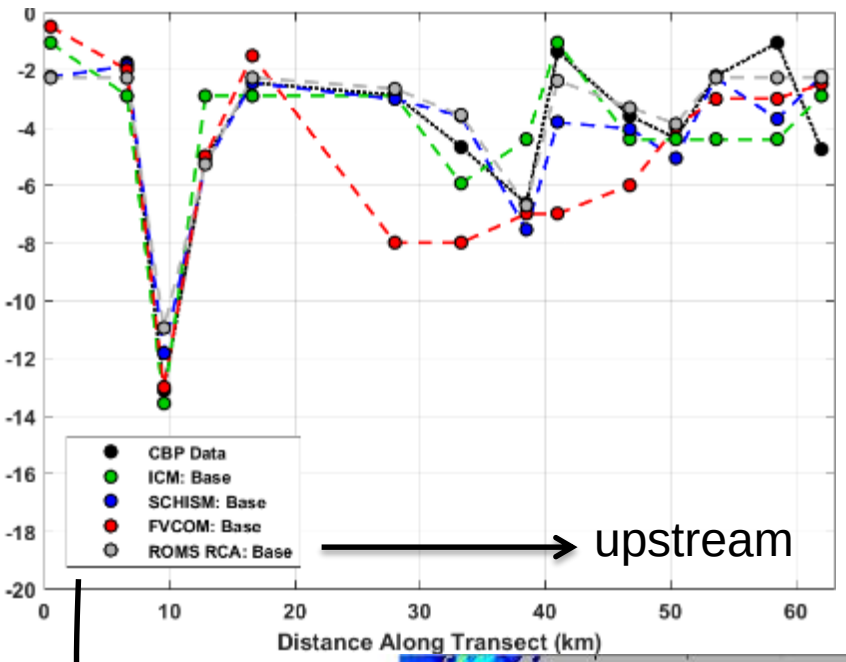


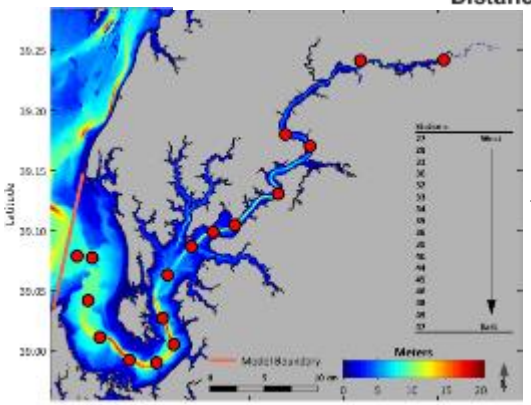
Thalweg depths also differ among models

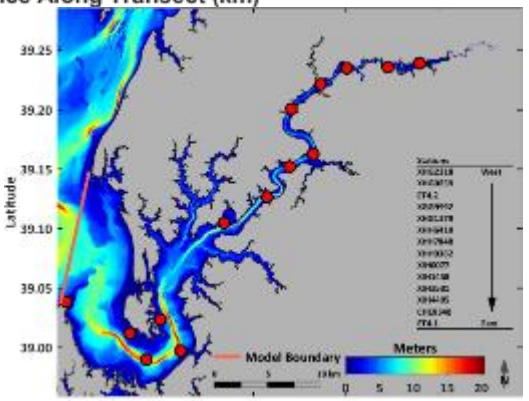
DEM Bathymetry – channel depths

Deepest CBP data





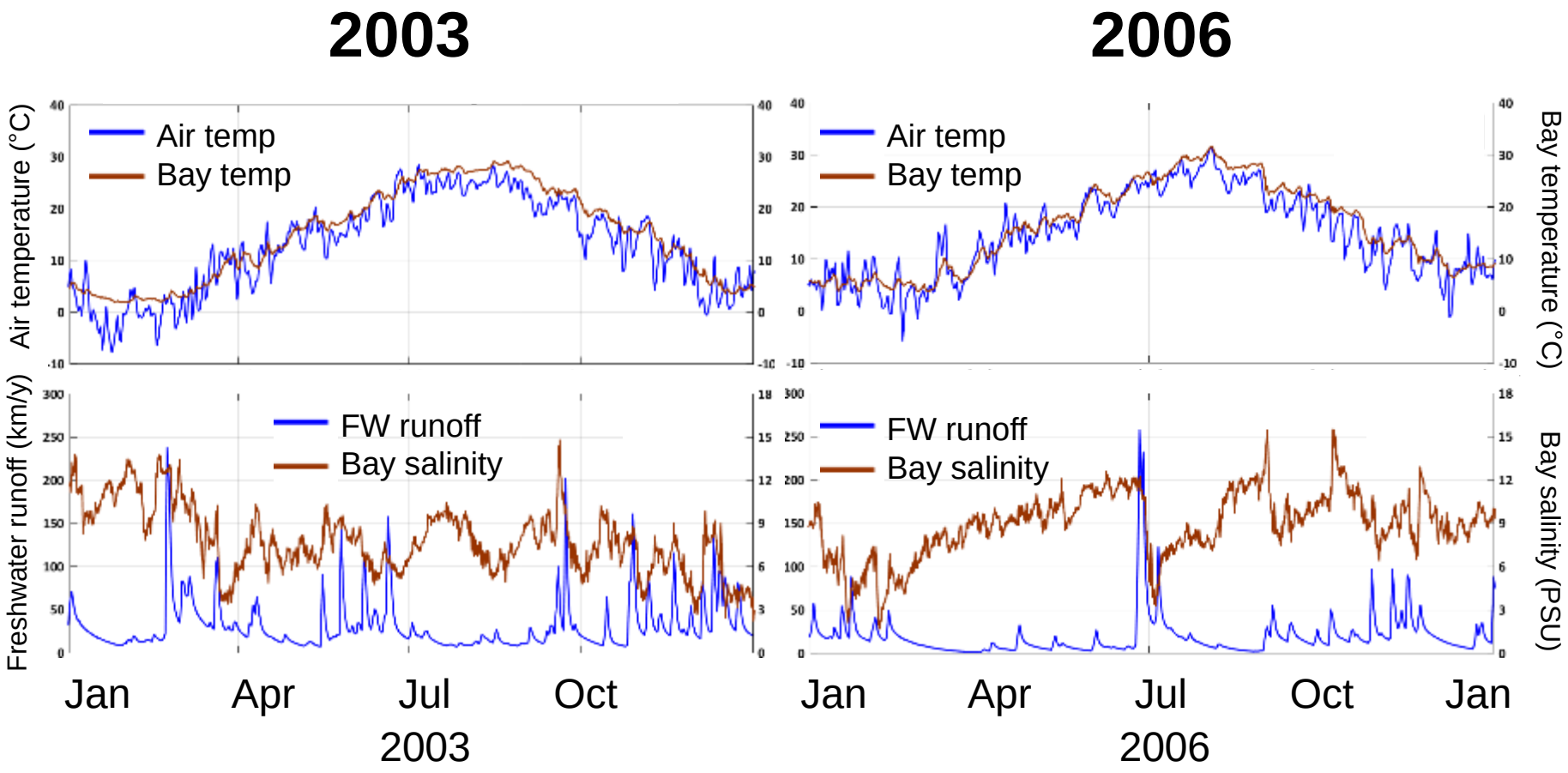




SCHISM closely follows DEM; FVCOM and CH3D-ICM are shallower.
ROMS-RCA, SCHISM & ICM closely follow data depths; FVCOM is deeper.

Chester River Hydrodynamic Model Forcing

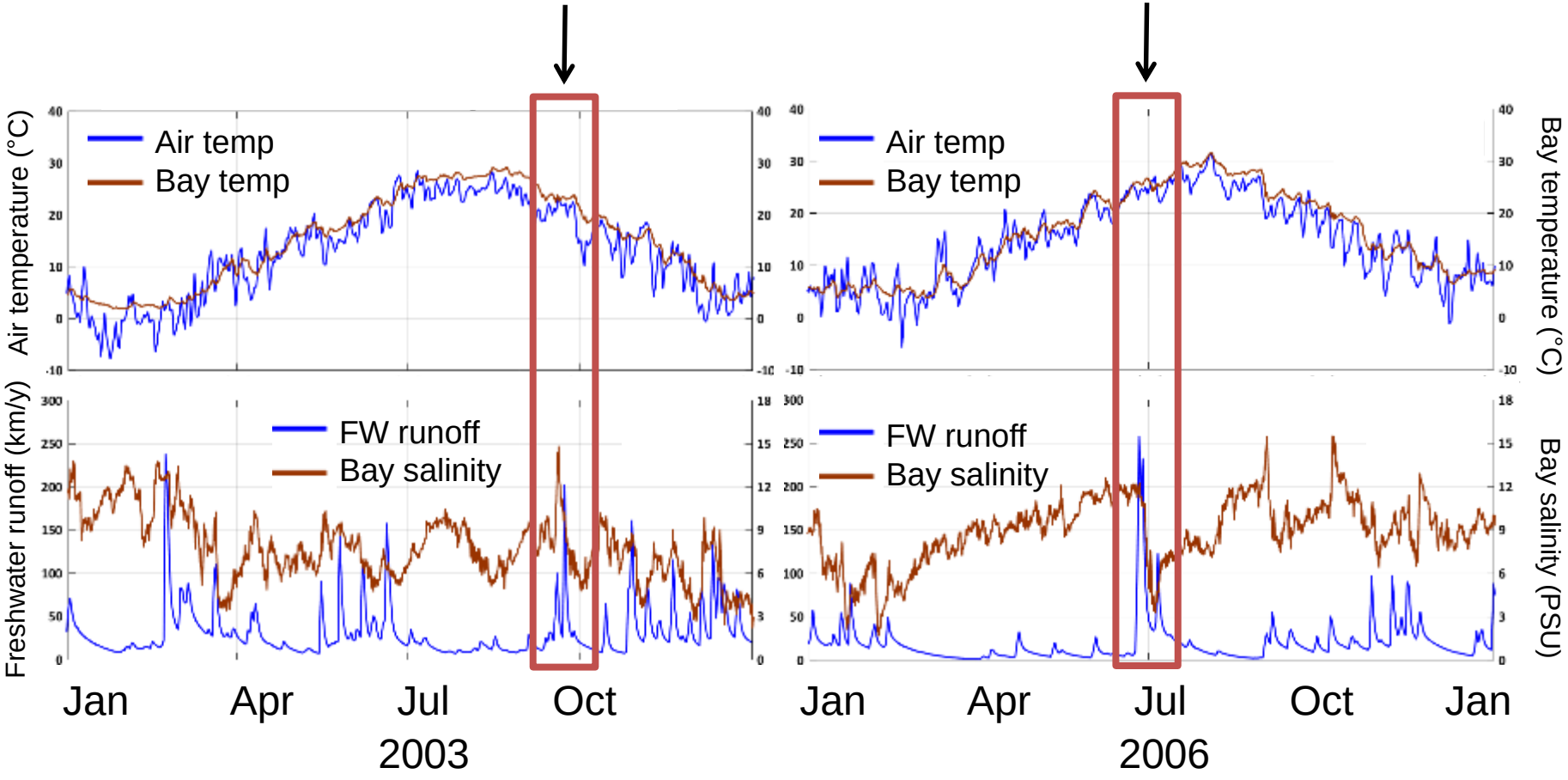
consistent for all models



Bay temperature and Bay salinity are obtained from the CH3D model, and the FW runoff is obtained from the CBP watershed model.

“Hurricane Isabel”

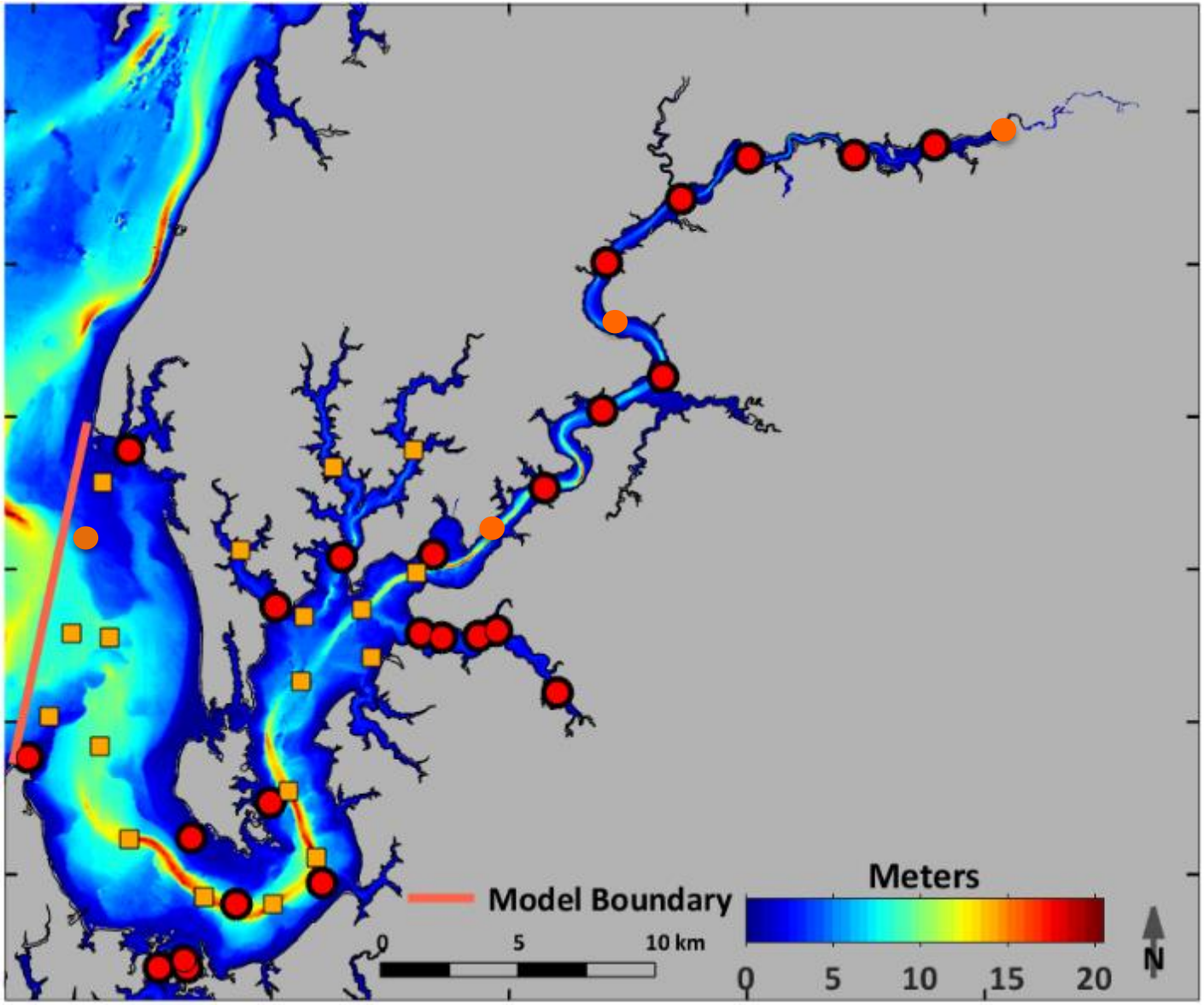
“Mid-Atlantic US Flood of 2006”



Response driven by salinity entering from Bay

Response driven by freshwater inflow

Requested model output at 50 stations (25 with data)



Simulation Experiments

Requested three simulations (all for 2003-2006) for hydrodynamics (S, T) and water quality (chl, DO,TSS):

1) Base Case
2) 10% reduction in watershed inflow
3) SCHISM Outer Boundary Condition (OBC) in place of CH3D OBC

Available Model Simulations

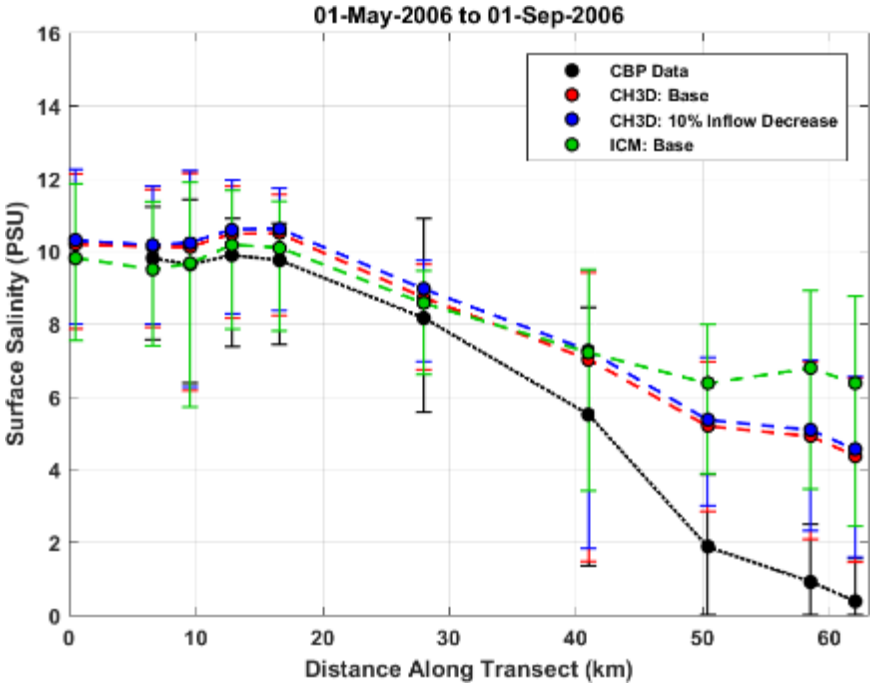
Model	years	base case	OBC expt	reduced flow expt
CH3D	2003-266	TS		TS
CH3D-ICM	2003-2006	TS & WQ		TS
CH3D-ICMp5.3.2	2003-2005	WQ		
FVCOM-ICM	2003-2006	TS & WQ	TS & WQ	TS & WQ
ROMS (RCA)	2003 (25 stas)	TS		
SCHISM-ICM	2003-2006	TS & WQ	TS	TS

Part 1: Hydrodynamics (T&S)

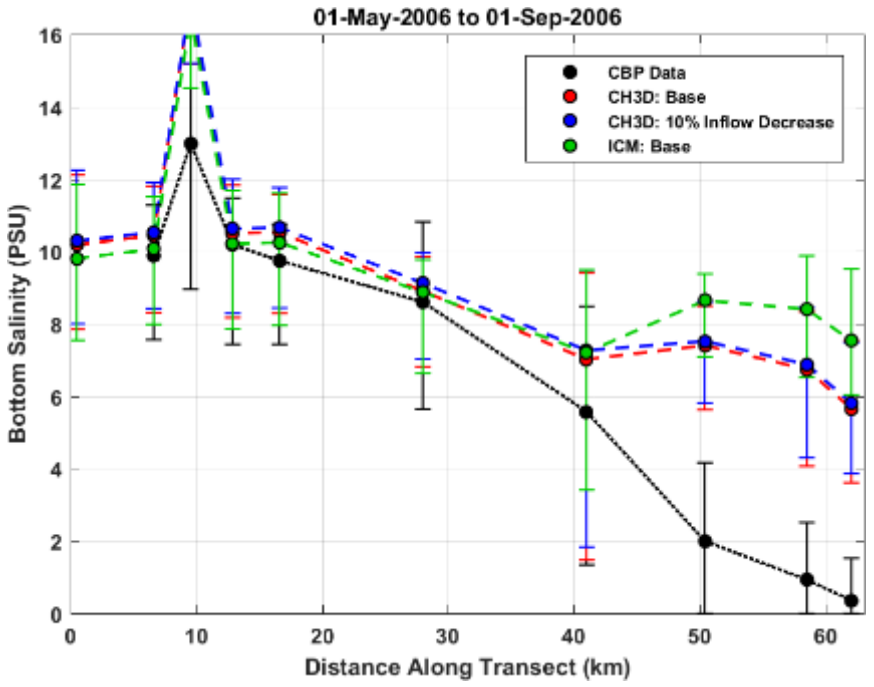
A. Base Case Comparisons

ICM salinity vs. CH3D salinity

Surface Salinity

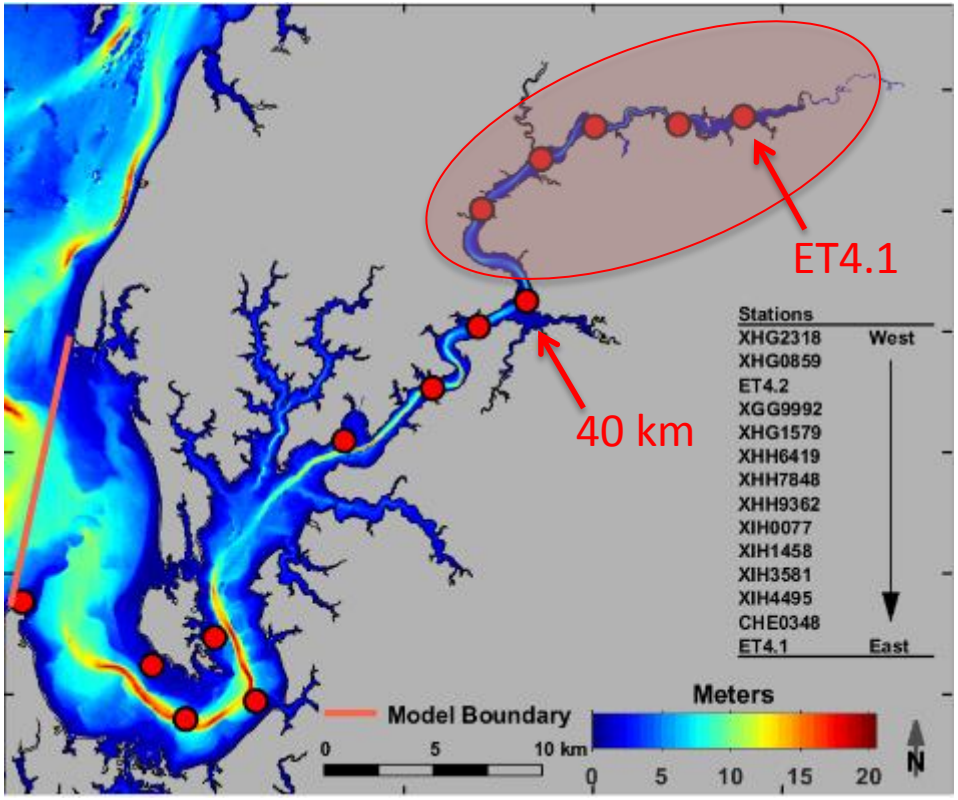


Bottom Salinity



In first 40 km → small difference between ICM & CH3D (ICM slightly better)
In upper Chester → large difference between ICM & CH3D (CH3D much better)

ICM salinity vs. CH3D salinity



ICM and CH3D differ by 2 psu beyond 40km from mouth

Salinity at ET4.1 [psu]

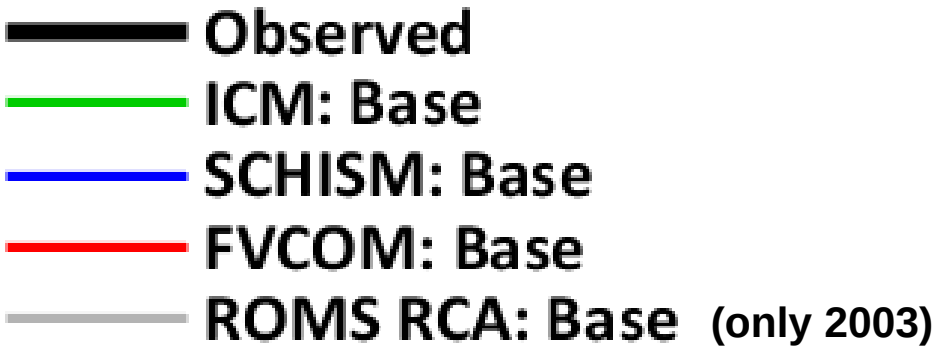
	CH3D	ICM
Surface 2003	2	4
Bottom 2003	3	5
Surface 2006	4	6
Bottom 2006	6	8

Data indicate no salinity stratification and ~0-0.5 psu

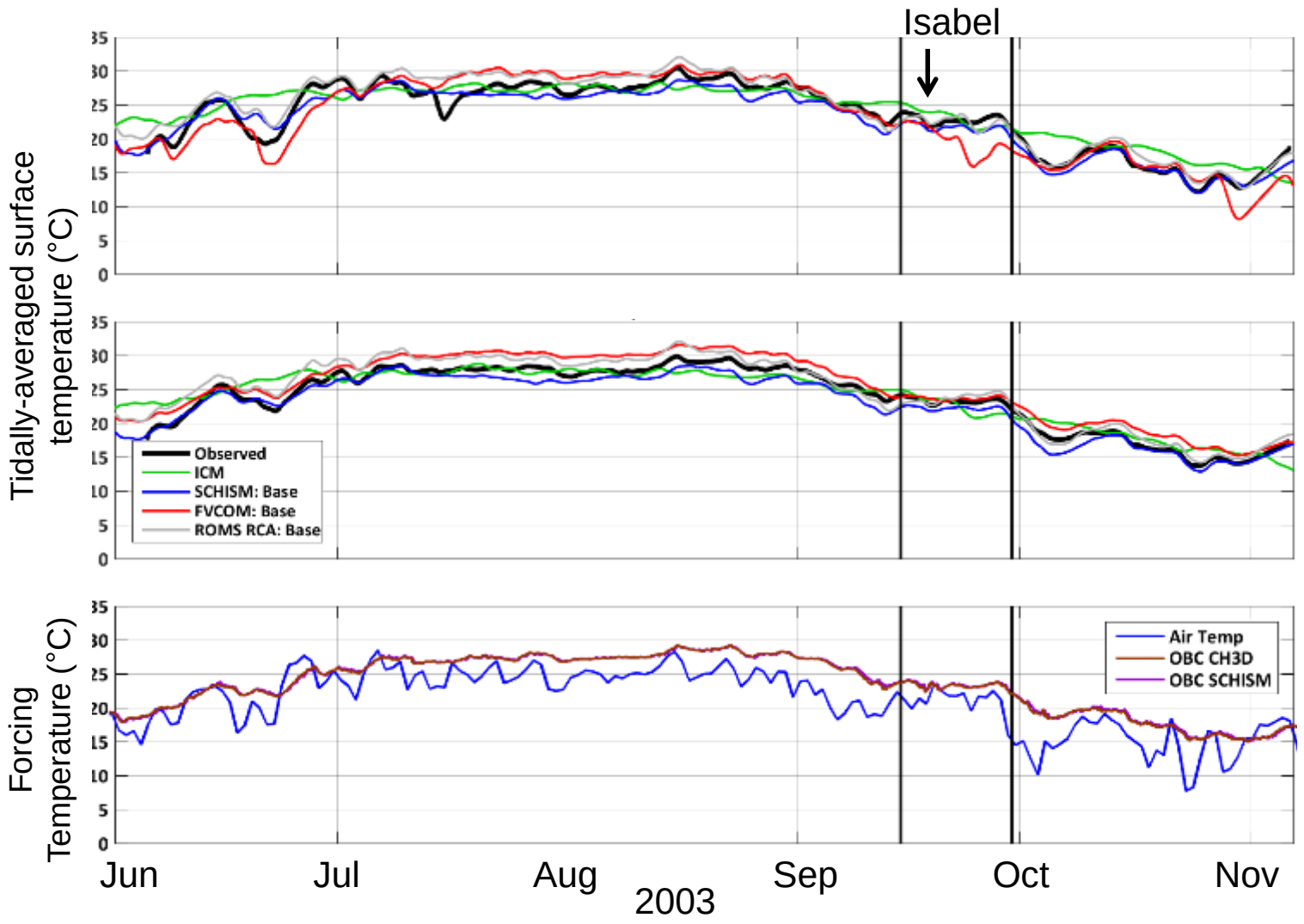
→ Use CH3D T&S for OBC fields

→ Use ICM T&S for comparisons

Can our shallow water models reproduce observed hydrodynamics (T, S) in the Chester River under normal conditions and during extreme events driven by tidal surge and freshwater inflow?



Model results – temperature



Sta. A upper Chester

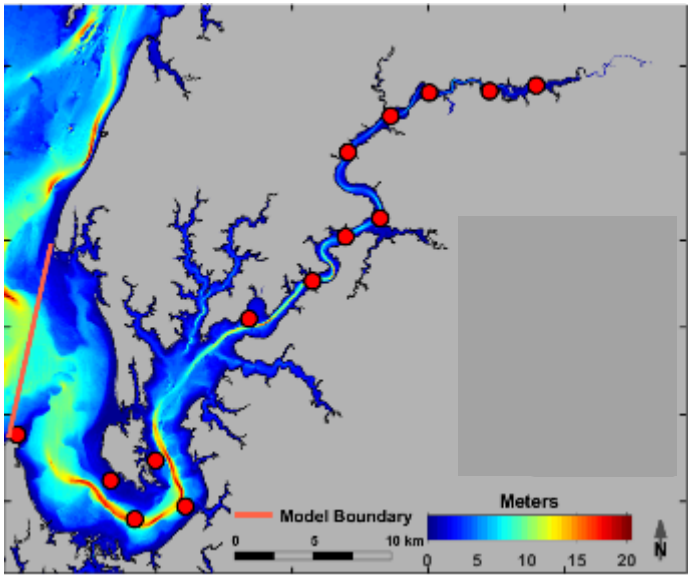
Sta. B mid-Chester

Forcing Temp. fields

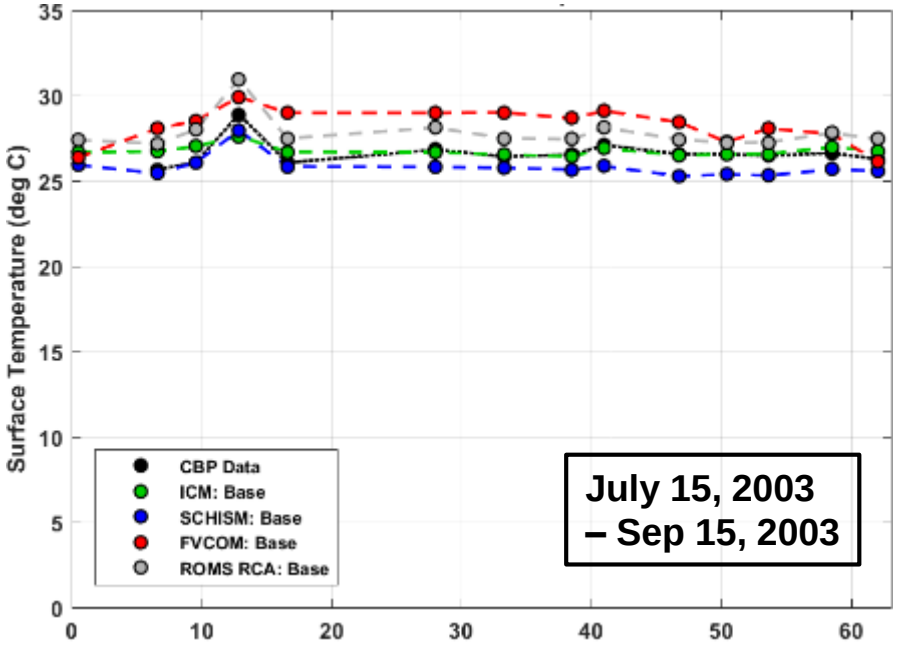
- Models simulate T well, as long as realistic forcing is used
- Results appear insensitive to grid resolution
- Model skill is generally same before, during and after Isabelle

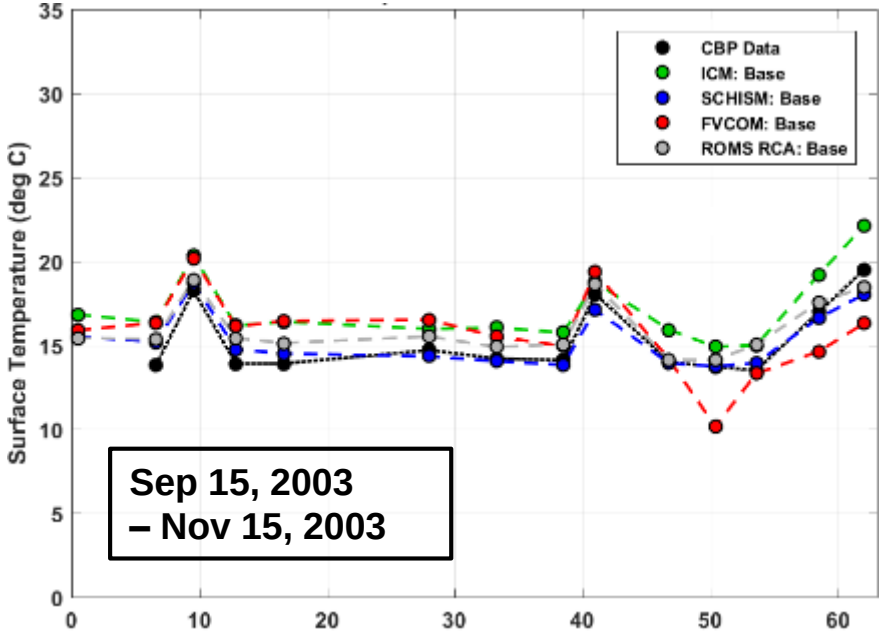
Model results – temperature

- Generally models simulate T well throughout transect
- Except in upper Chester where FVCOM is too cold and ICM is too warm by 3-4°C in Fall 2003
- Model skill is generally same before & after events



Surface Temperature

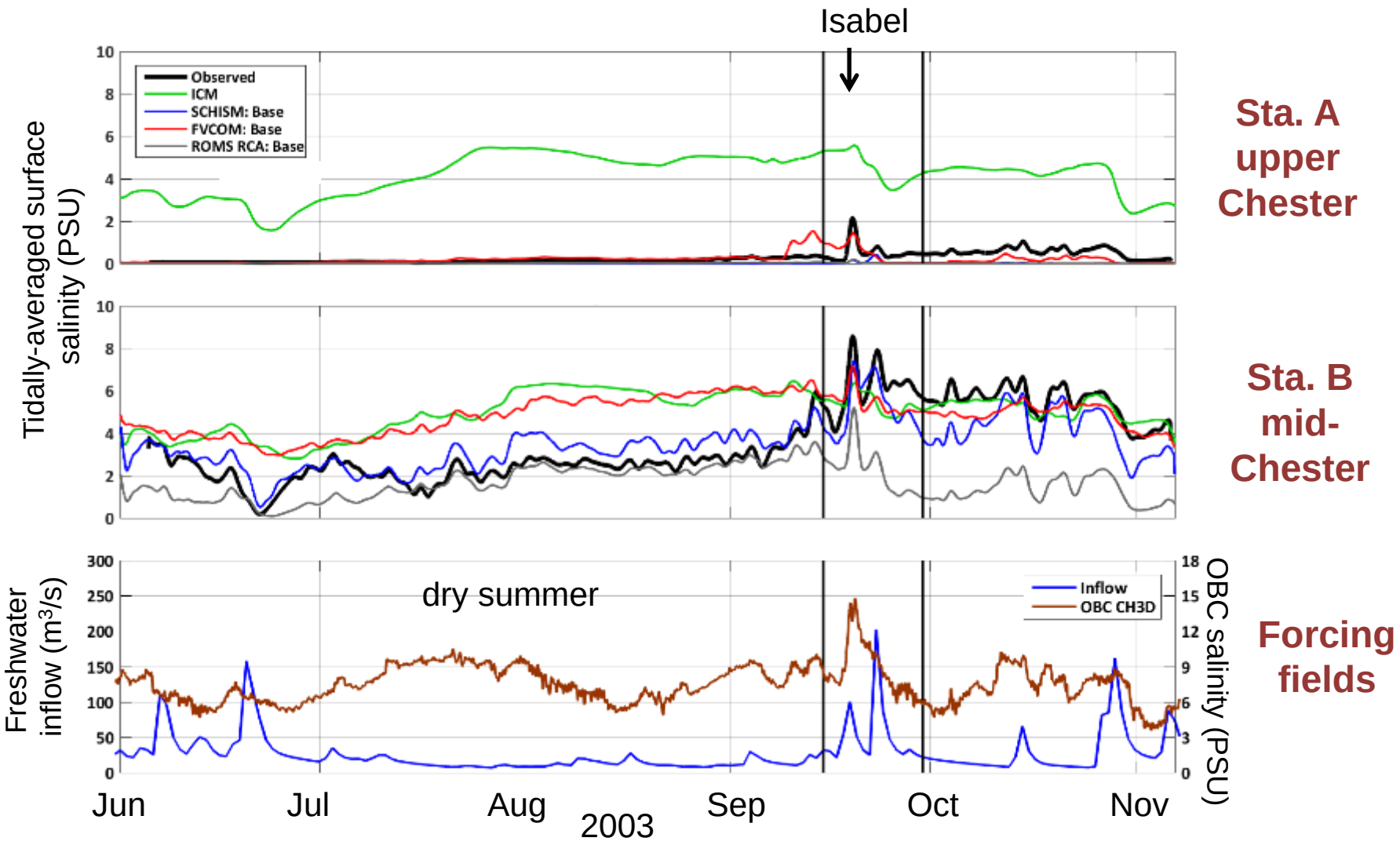




Bay → upstream

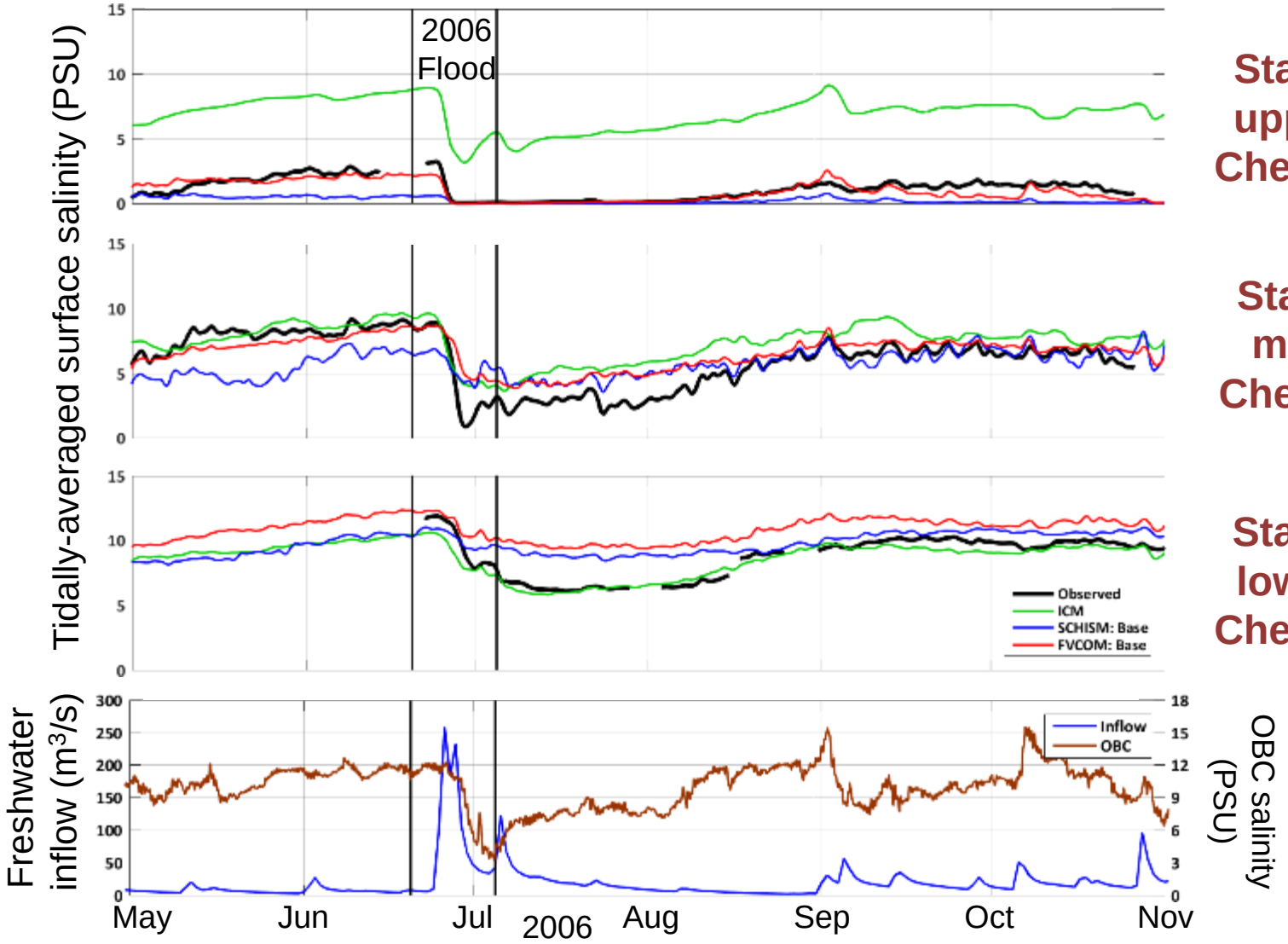
Bay → upstream

Model results – salinity – 2003



- Large differences between models (low res. model is too salty in upper Chester)
- Event response - Only SCHISM produces strong pulse in salinity in mid-Chester, but response is short-lived
- No models produce strong salinity pulse in upper Chester

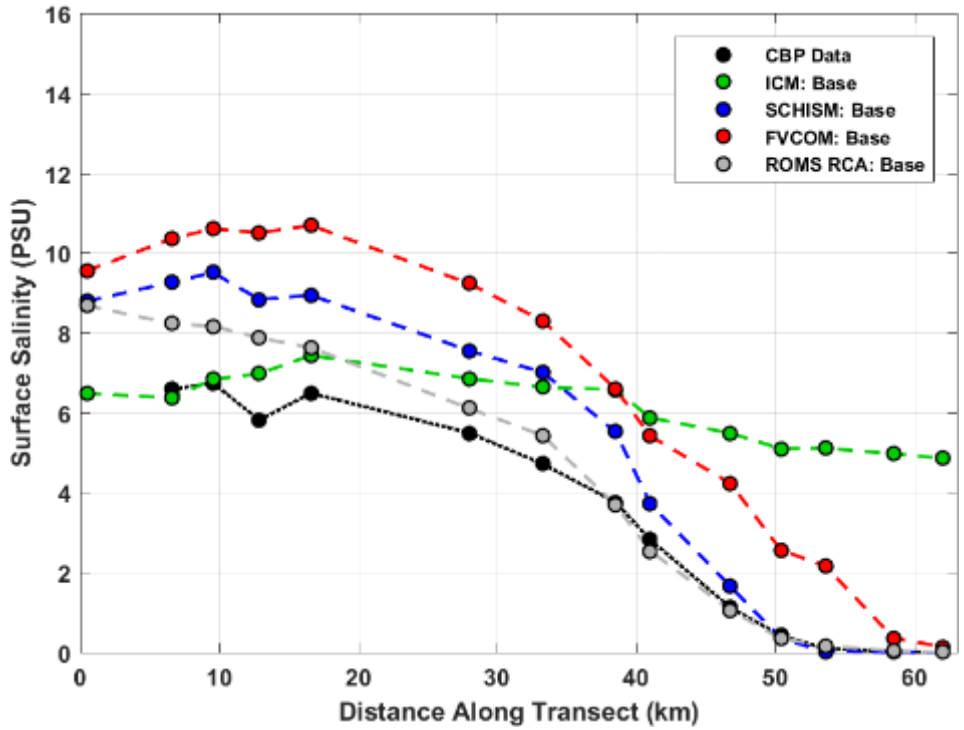
Model results – salinity – 2006



- ICM misses upstream salinity gradient; does **very** well in lower Chester
- FVCOM reproduces salinity at the uppermost station
- Models show a clear response to the freshwater pulse, but is too weak at mid & lower Chester stations; CH3D-ICM reproduces pulse very well

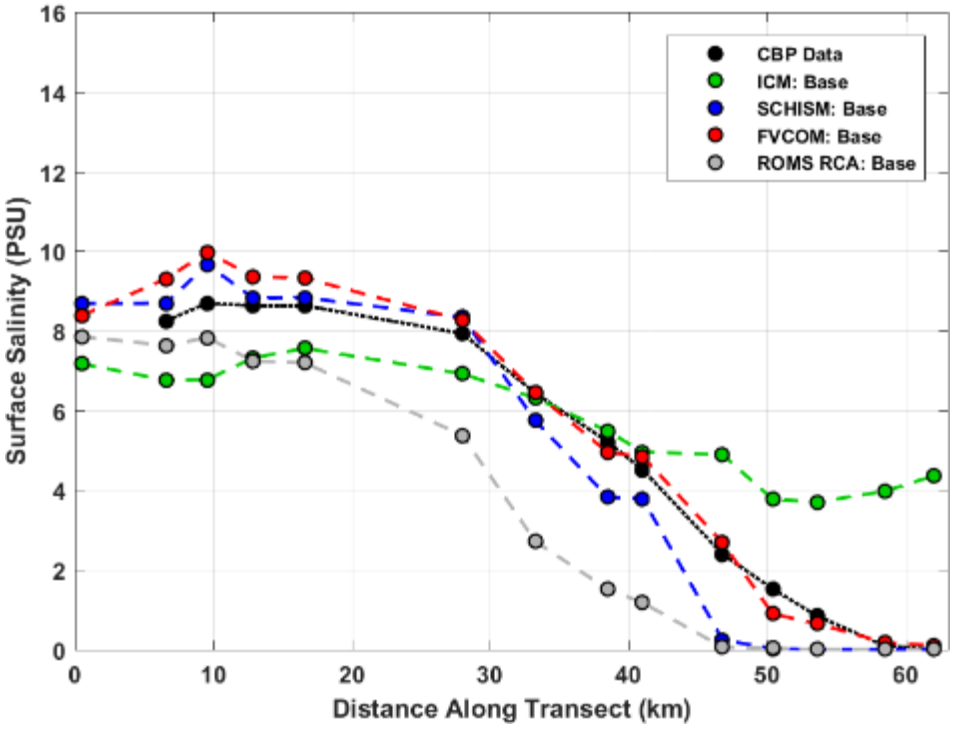
Model results – salinity – 2003

Summer 2003



Bay → upstream

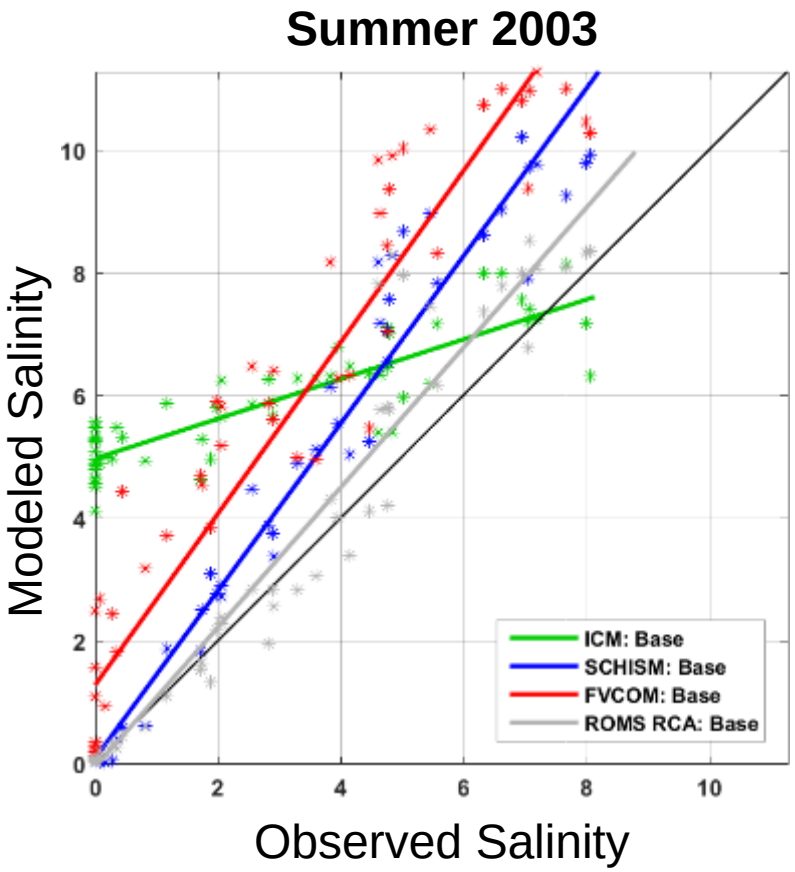
Fall 2003

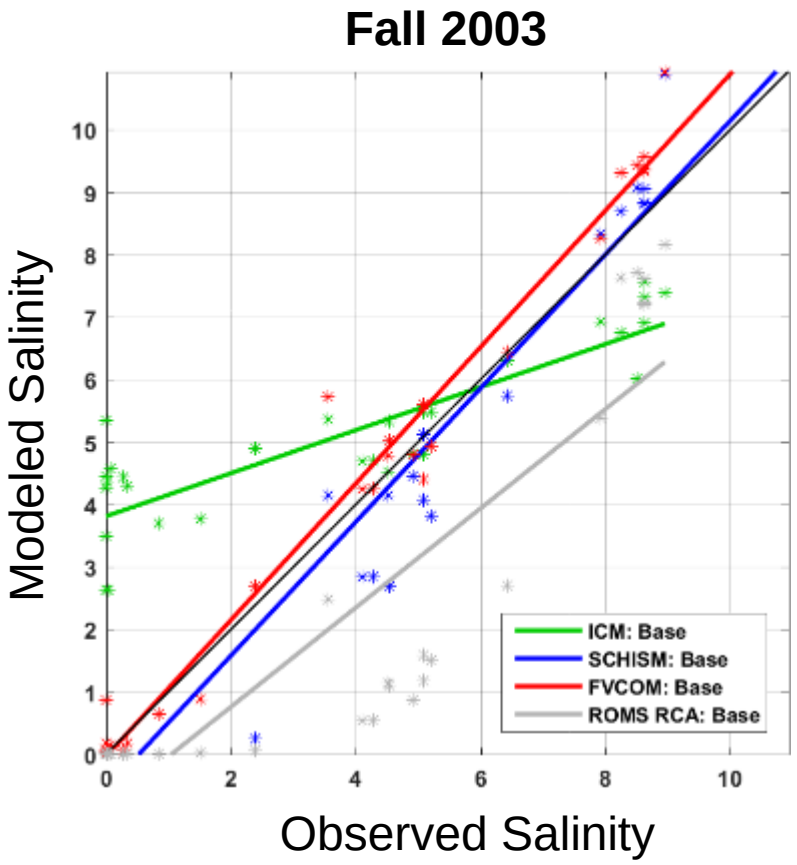


Bay → upstream

- ICM overestimates surface salinity in upper half of Chester
- FVCOM is always saltier than SCHISM
- Summer 2003: ROMS performs best
- Fall 2003: FVCOM and SCHISM perform best
- CH3D OBC is too high (9-10psu) in summer 2003?

Model results – salinity – 2003





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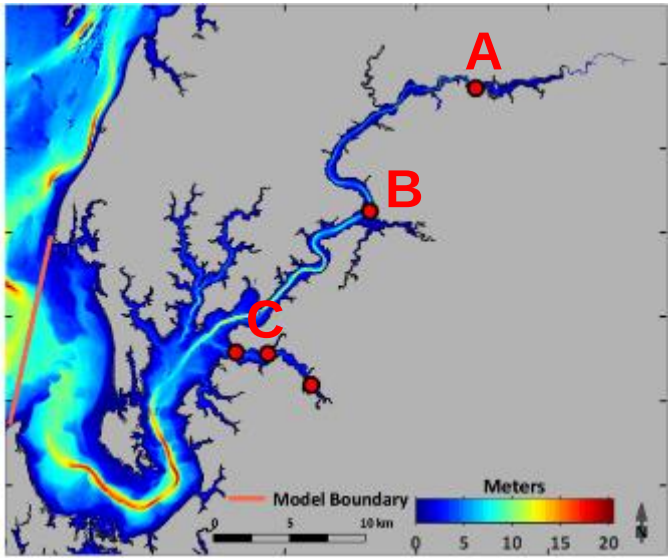
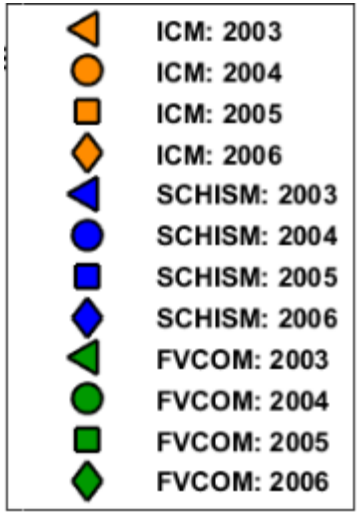
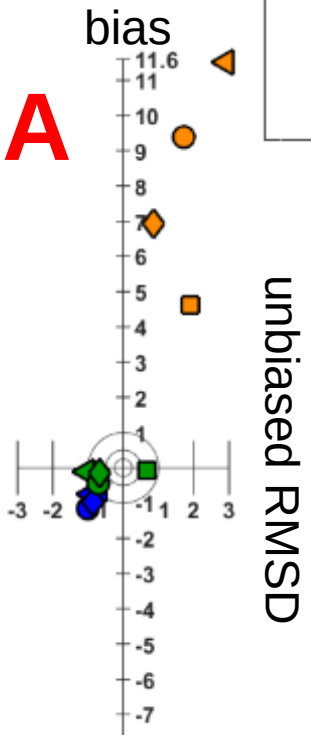
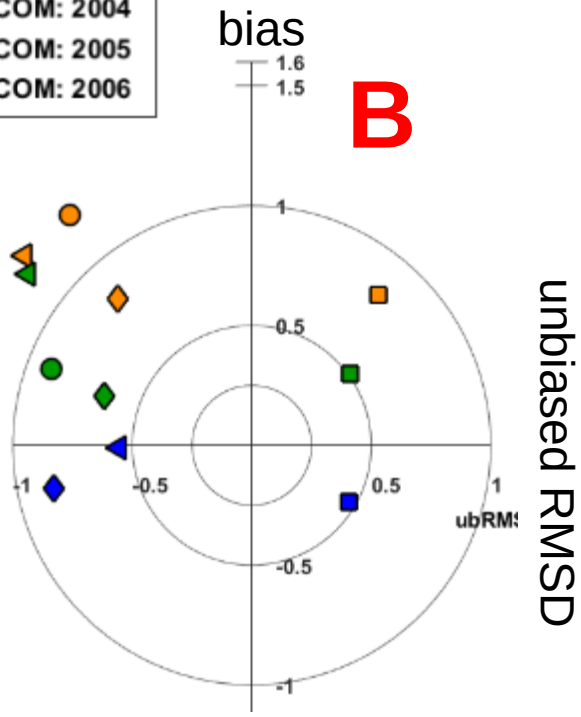
Salinity: 2003-2006



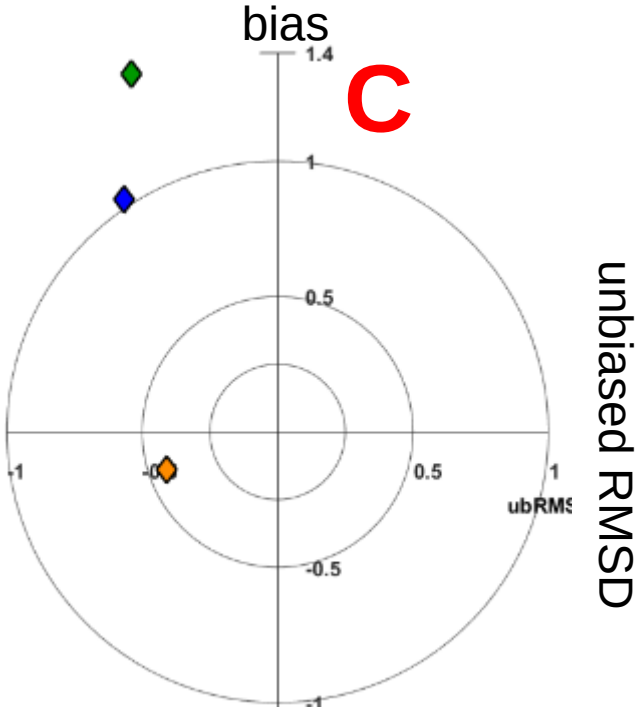




FVCOM does best in upper Chester



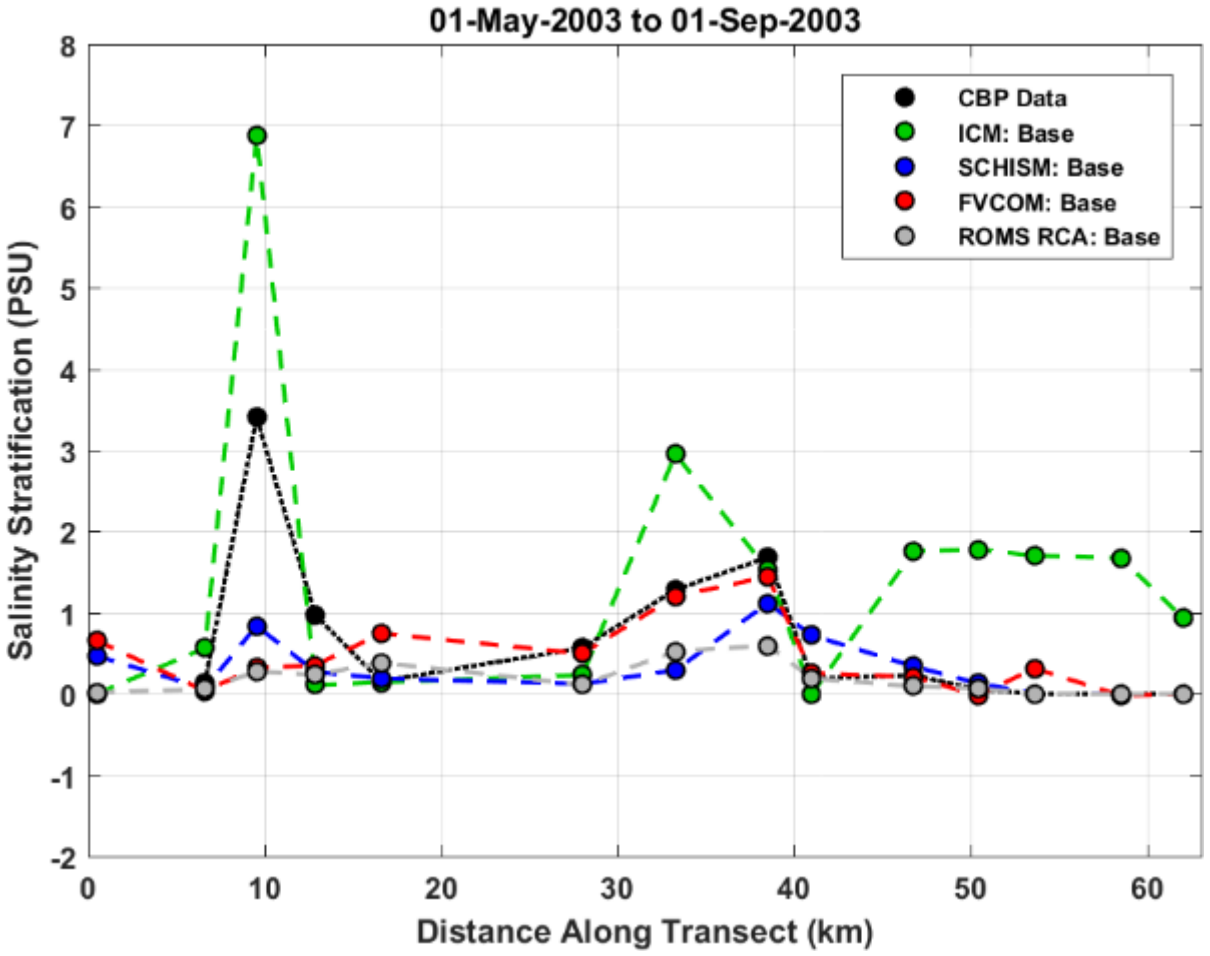
SCHISM does best in mid-Chester



ICM does best in lower Chester

Stratification: 2003 transect

Stratification = bottom S minus surface S

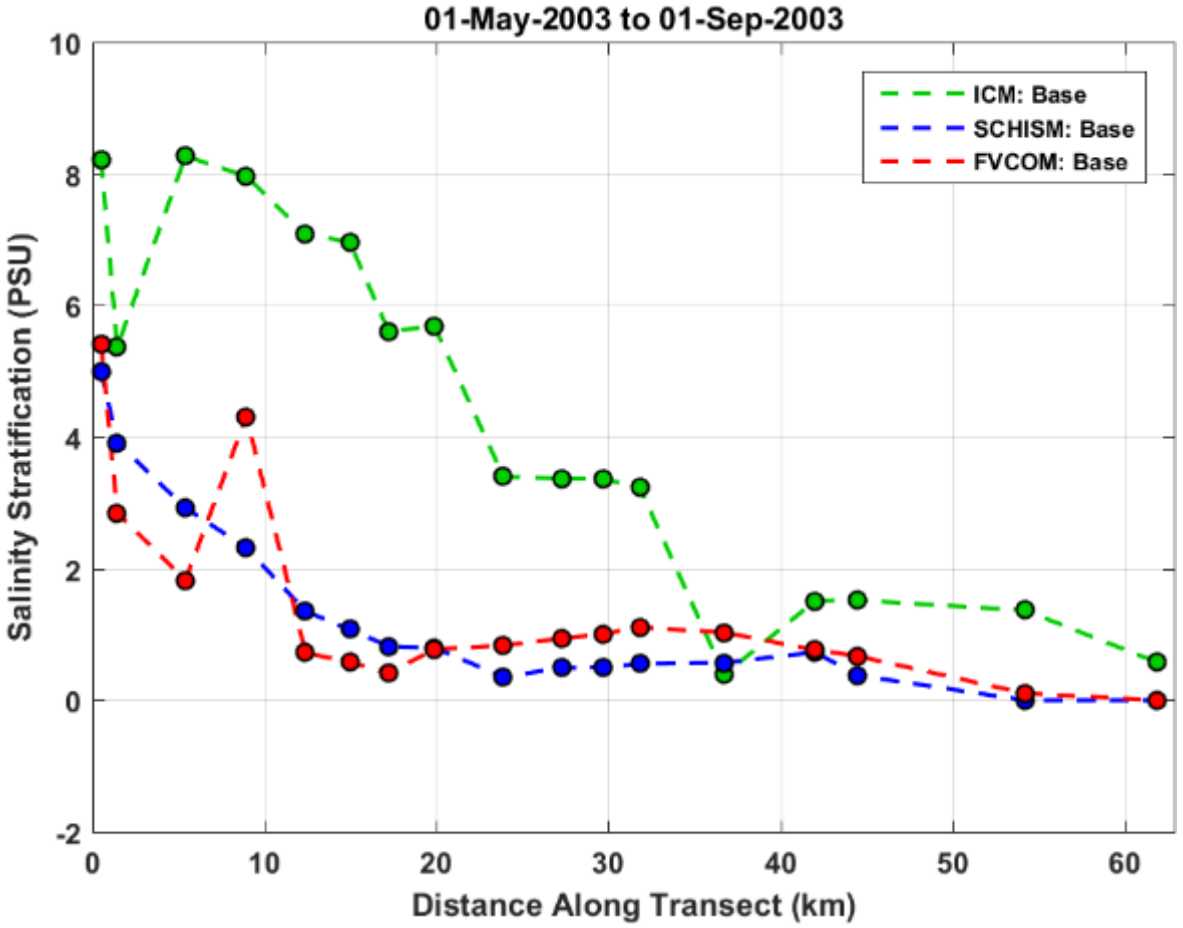


ICM overestimates stratification

ROMS & SCHISM often underestimate stratification

Stratification: 2003 transect along channel

Stratification = bottom S minus surface S



ICM generates much more stratification throughout Chester

Part 1: Hydrodynamics (T&S)

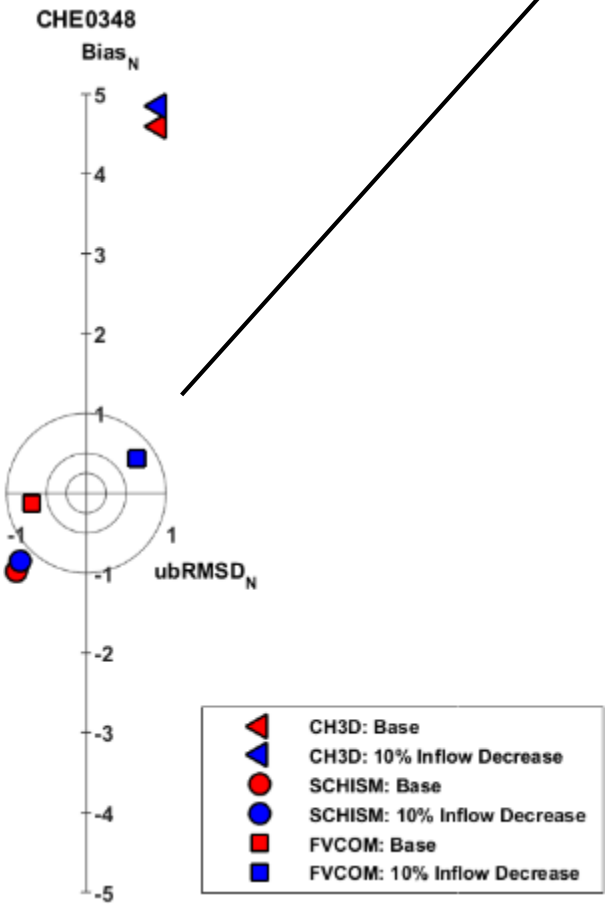
B. Sensitivity Experiments

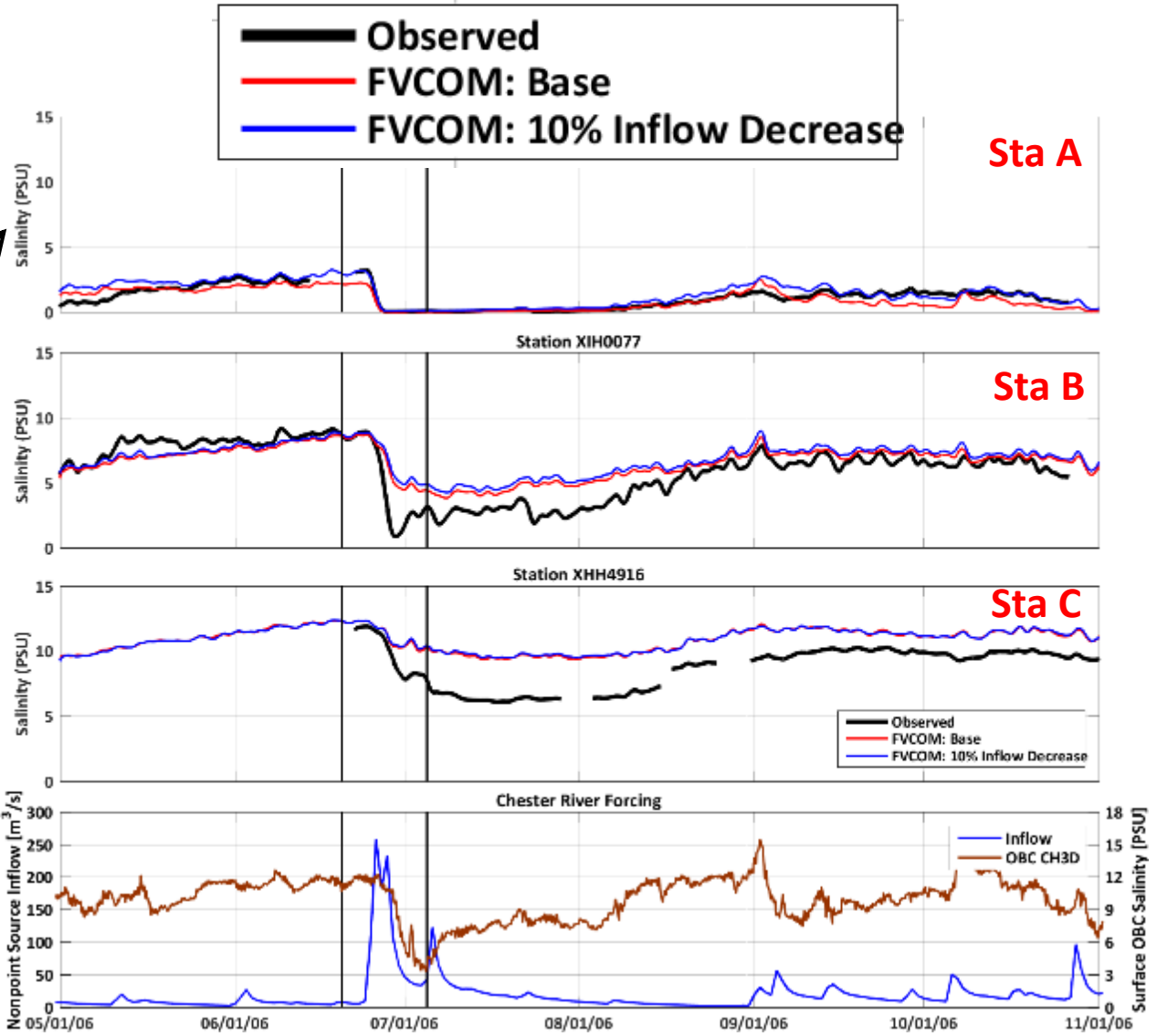
→ 10% decrease in freshwater inflow

→ SCHISM vs. CH3D Outer Boundary Conditions

Effect of 10% Flow reduction: FVCOM as an example (2006)

- A 10% inflow reduction has little effect on modeled salinity





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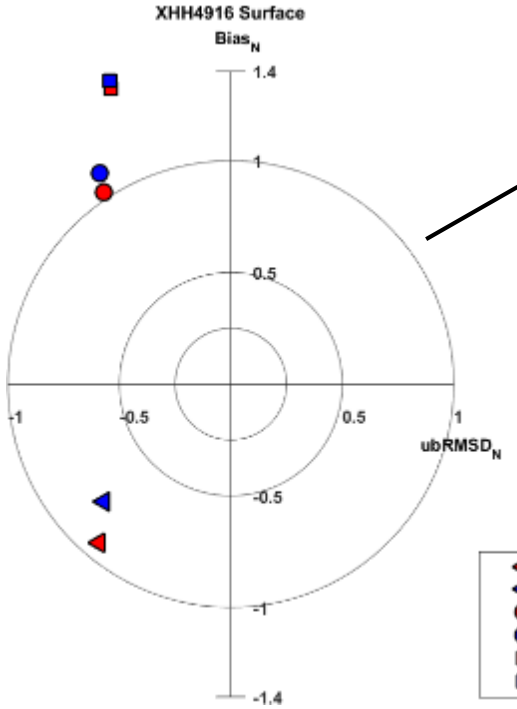
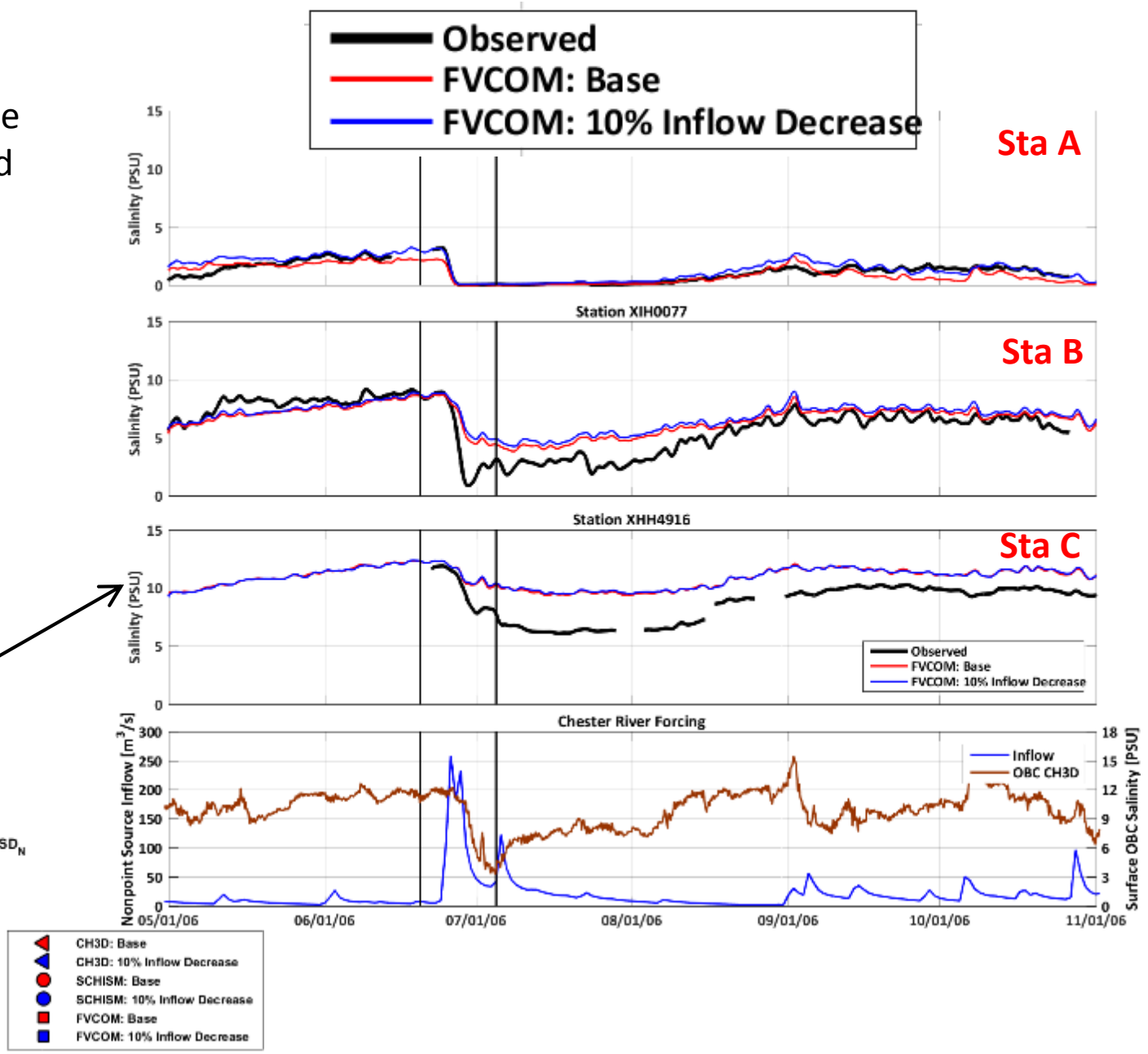
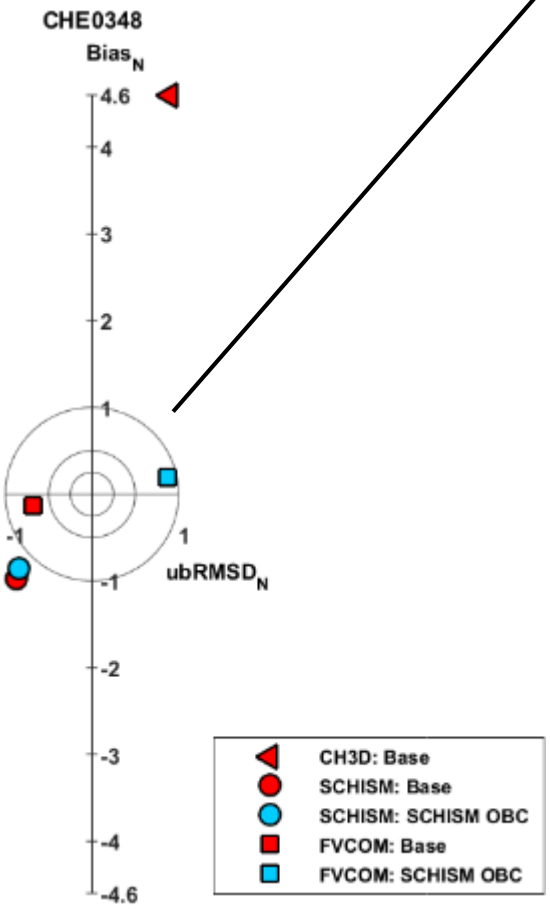
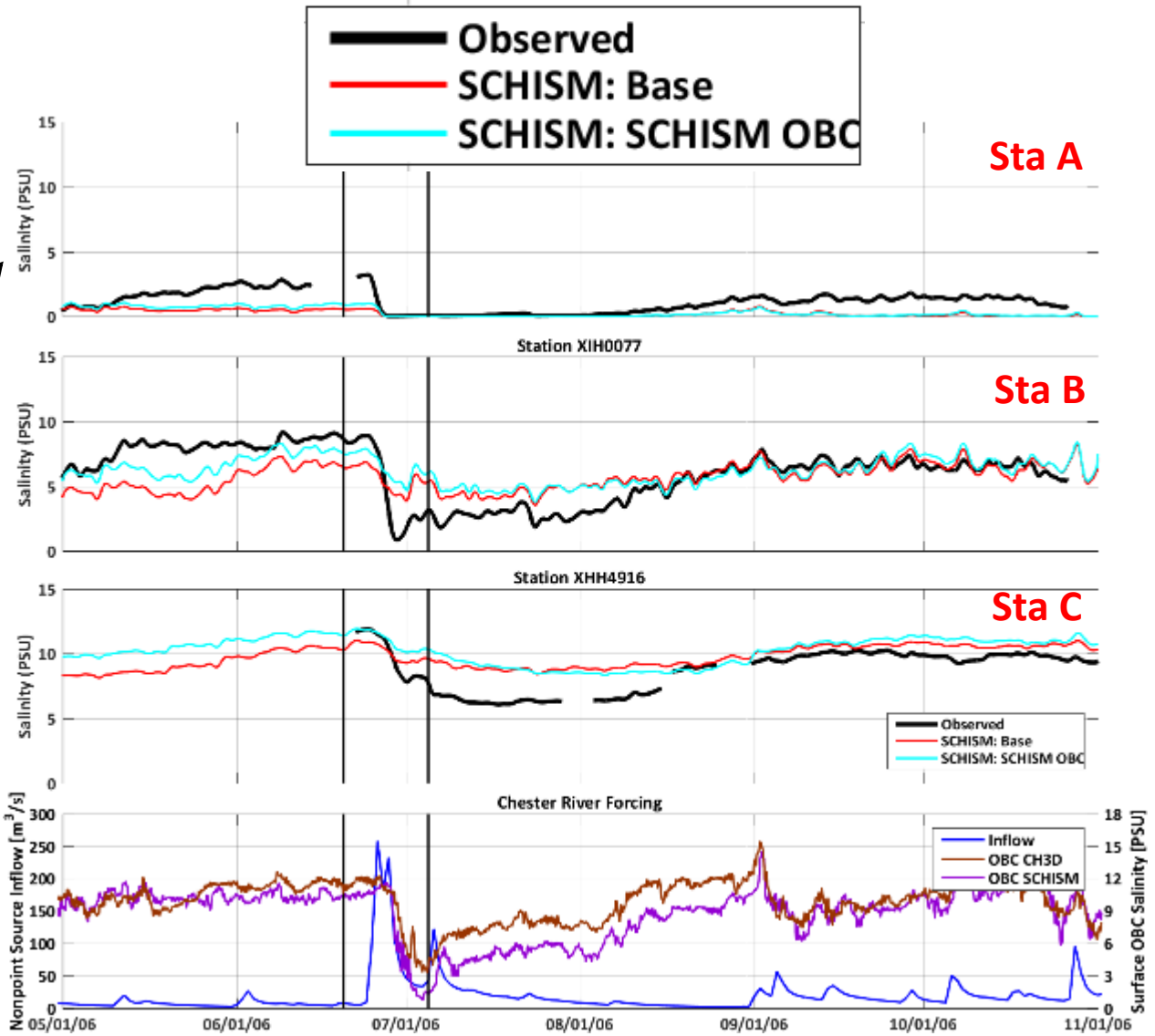




Effect of changing OBC: SCHISM as an example (2006)

- A change from CH3D OBC to SCHISM OBC has largest effect in early summer





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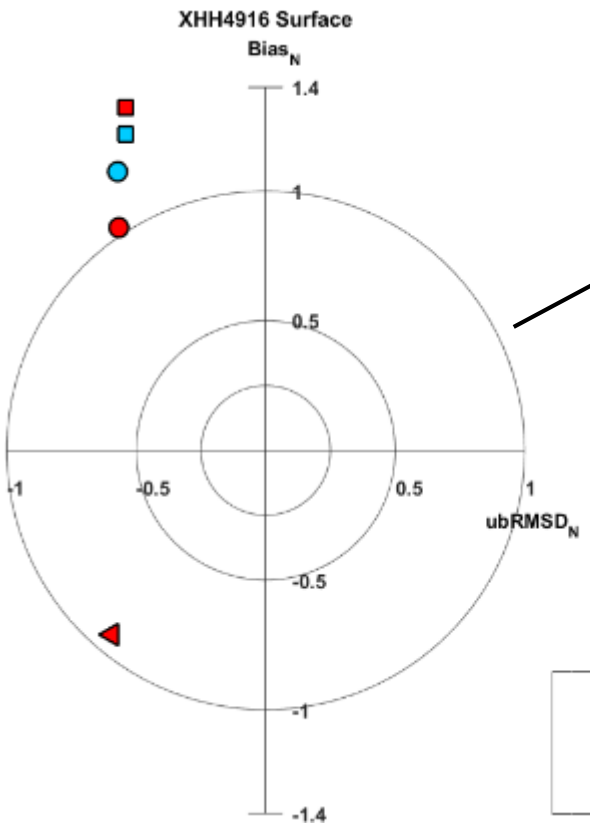
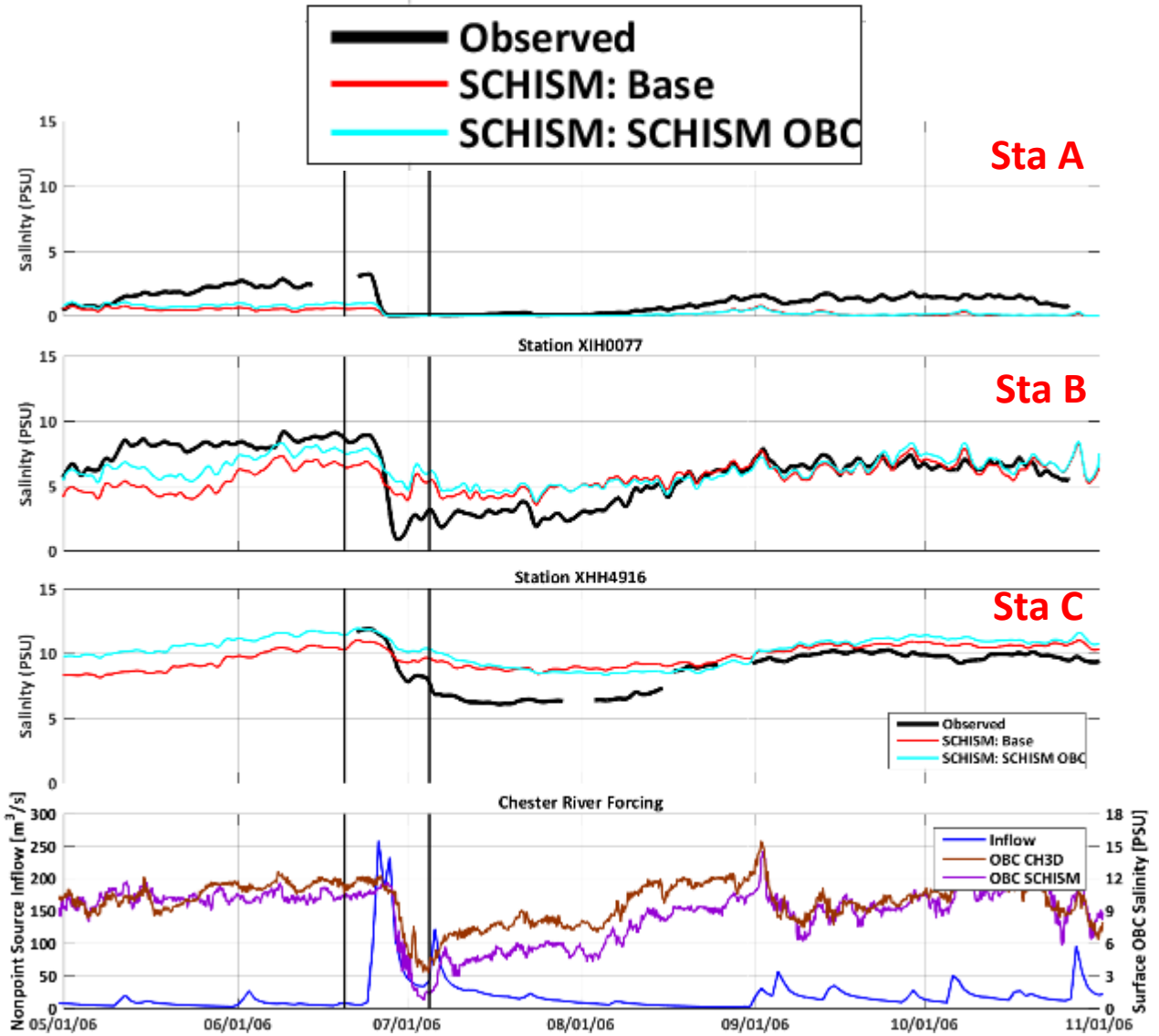
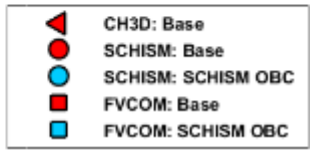
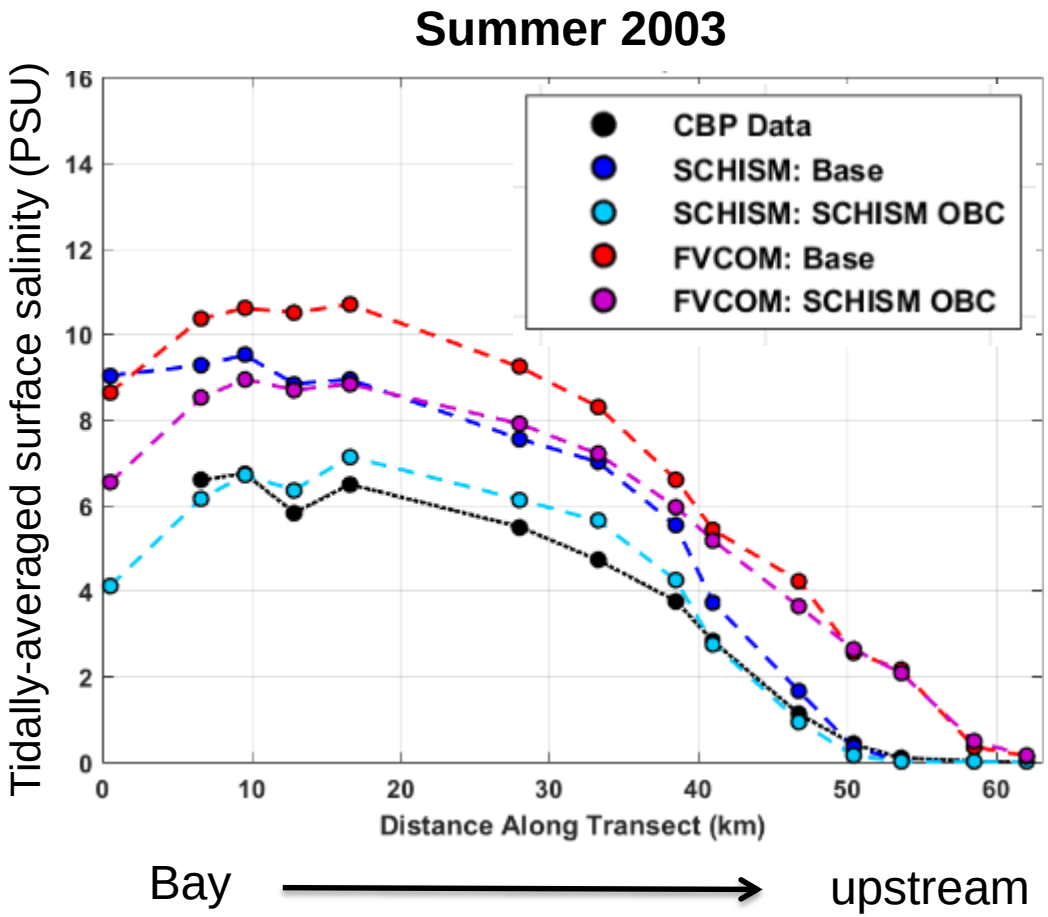






Effect of changing OBC on surface salinity



- Effect of OBC is felt 45 km up the tributary in summer
- *Note: FVCOM+SCHISM OBC salinity at 0km does not match SCHISM+SCHISM OBC results at 0km*

Summary of Hydrodynamic Results

1. **Models simulate temperature well**
   - → Atmospheric temperature & wind forcing are required
   - → High resolution grid is not required

2. **Simulating salinity is more challenging**
   - → Low resolution models do not capture downstream salinity gradient
   - → CH3D salinity is better than ICM salinity in upper Chester
   - → FVCOM does best in upper Chester; SCHISM in mid-Chester; ICM in lower Chester
   - → ROMS does best in summer; FVCOM & SCHISM do best in fall
   - → No models produce salinity pulse into upper Chester during Isabel; responses in mid-Chester are too short-lived
   - → High resolution models do reasonably well for salinity stratification; ICM produces much stronger stratification throughout Chester

3. **Sensitivity experiments**
   - → 10% reduction of inflow has small effect
   - → Change in OBC is felt ~45km up Chester River, primarily in summer

Implications for Water Quality Management

- **If we are not correctly simulating distributions of a conservative tracer such as salinity, our physical processes (e.g. advection) are likely wrong**
  - → May have significant ramifications for nutrients and water clarity
  - → Must make sure our mixing/advection/physical processes are correct, to avoid tuning our water quality, biogeochemical and living resource models to make up for hydrodynamic model deficiencies

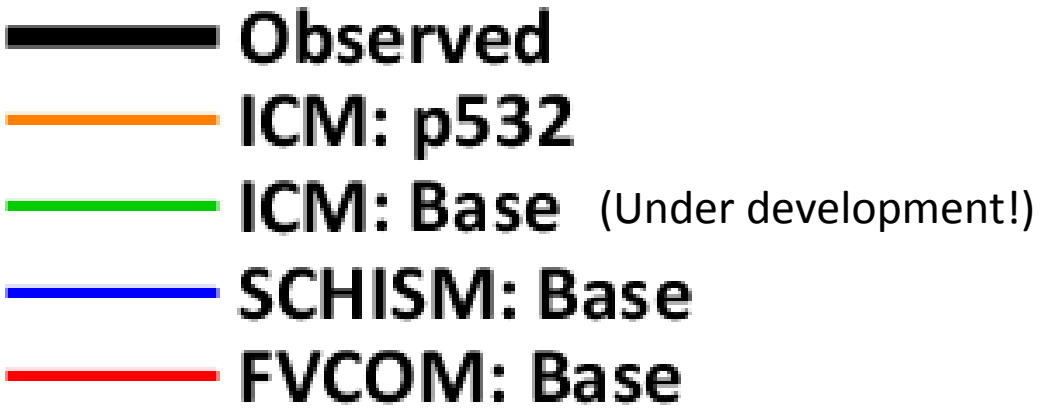
- **Information from open boundary travels ~45km up the tributary**
  - → Must have confidence in the simulation we use for our open boundary conditions!

- **Accurately simulating dynamic mixing processes during extreme events is critical**
  - → Effects of extreme events are long-lived (~2 months)
  - → More extreme events with future climate change

Suggestions for manuscript emphases are welcome!

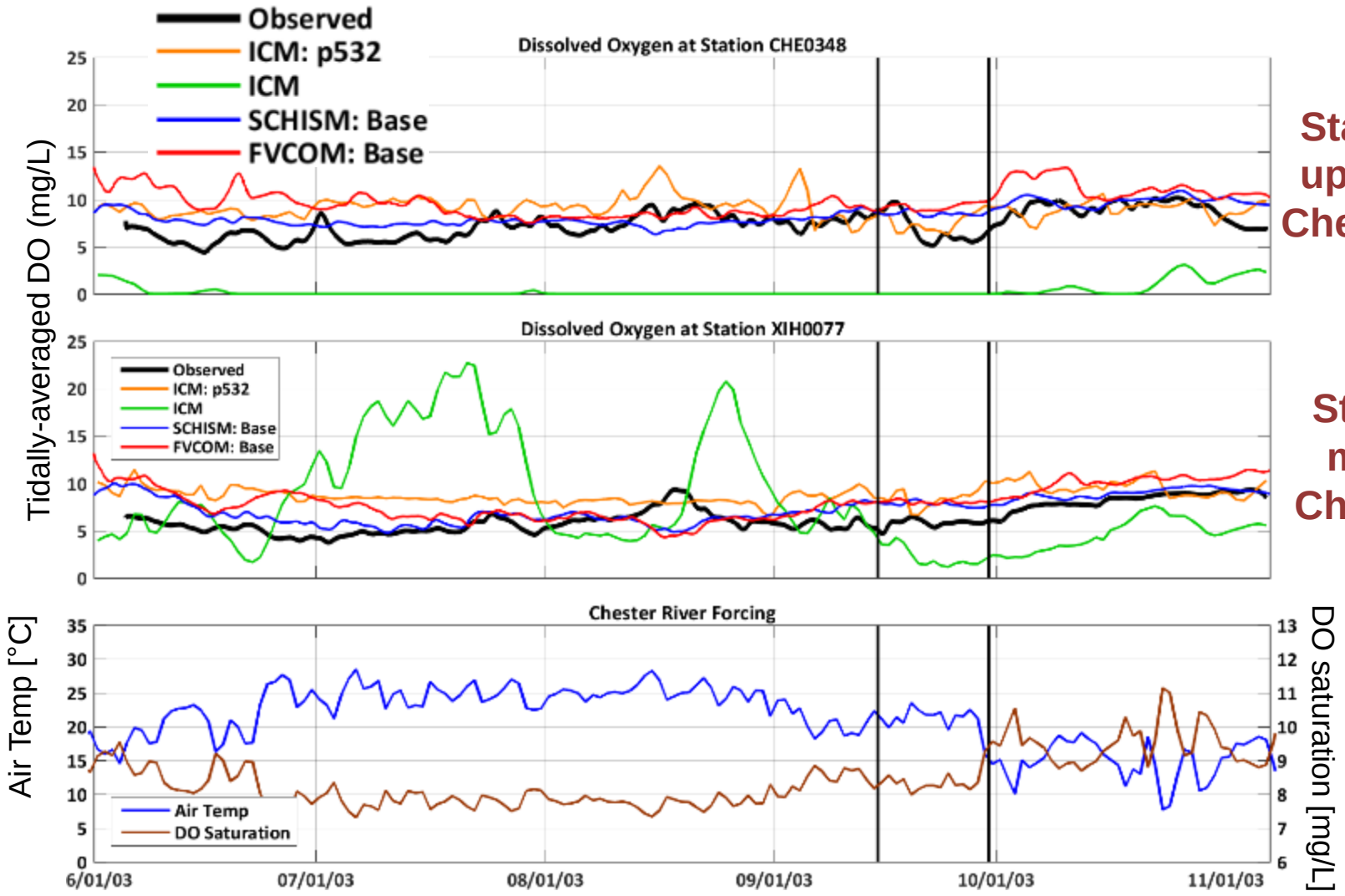
Part 2: Water Quality (DO, Chl, TSM)

A. Base Case Comparisons



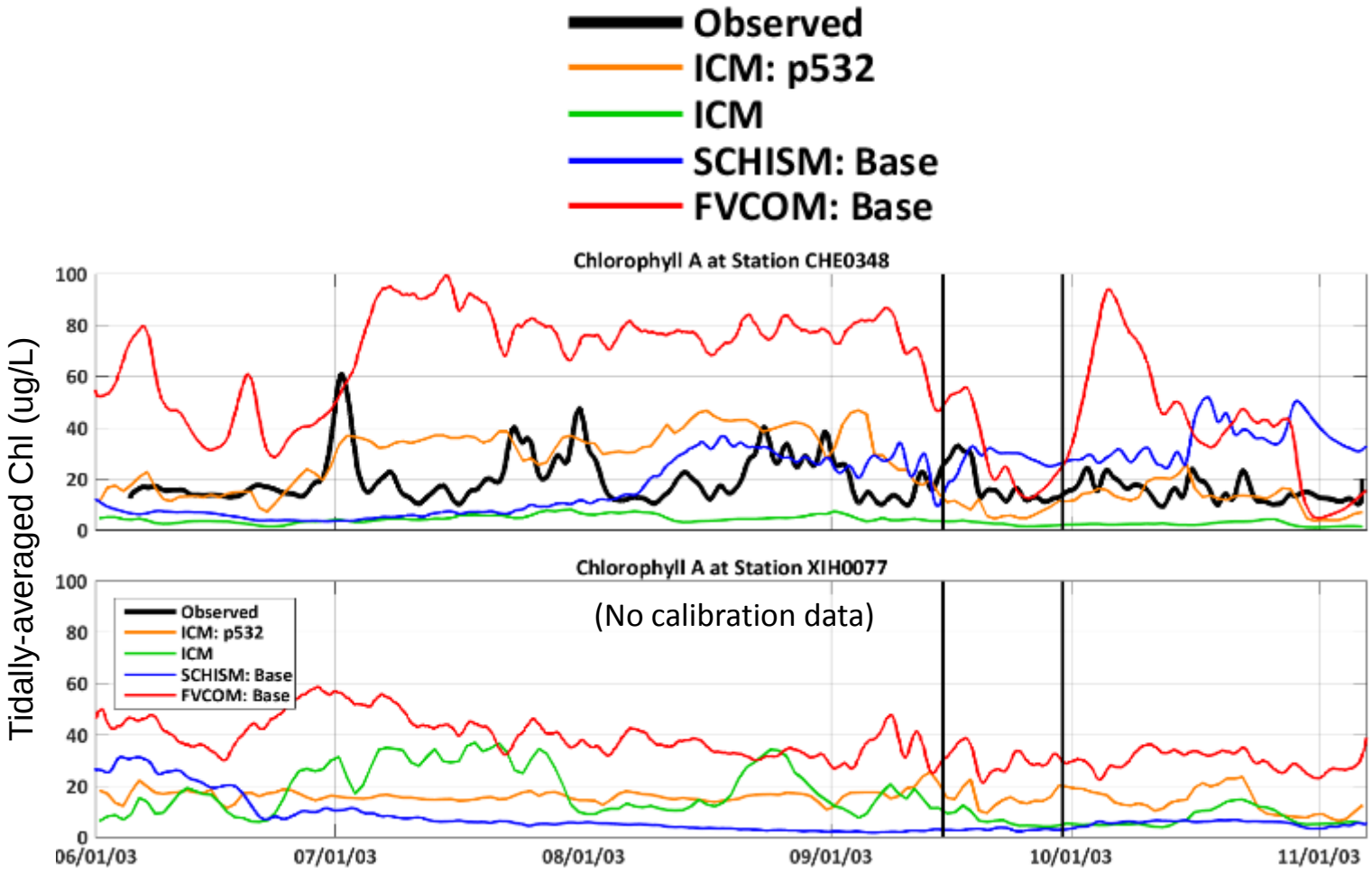
(A work in progress!!)

Tidal-averaged WQ variables: DO in 2003



- SCHISM, FVCOM & ICMp5.3.2 simulate DO quite well
- ICM-base is too anoxic in upper Chester; too high in mid-Chester during dry summer
- Models do not capture decrease in DO in upper Chester during Isabel

Tidal-averaged WQ variables: Chl in 2003



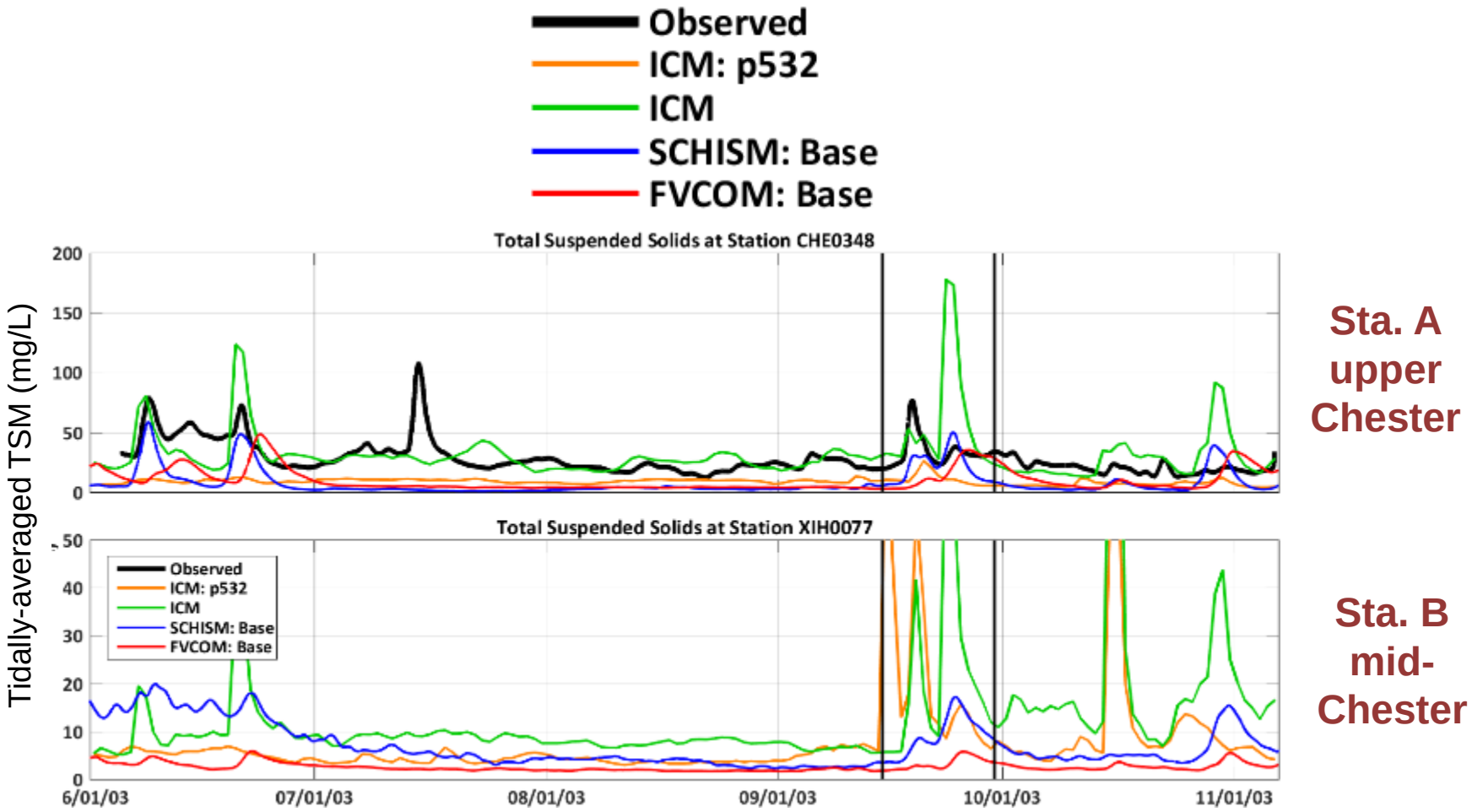
Sta. A upper Chester

Sta. B mid-Chester

In upper Chester:

- FVCOM Chl is too high
- SCHISM is low during dry summer
- ICMp5.3.2 does much better than new ICM base

Tidal-averaged WQ variables: TSM in 2003

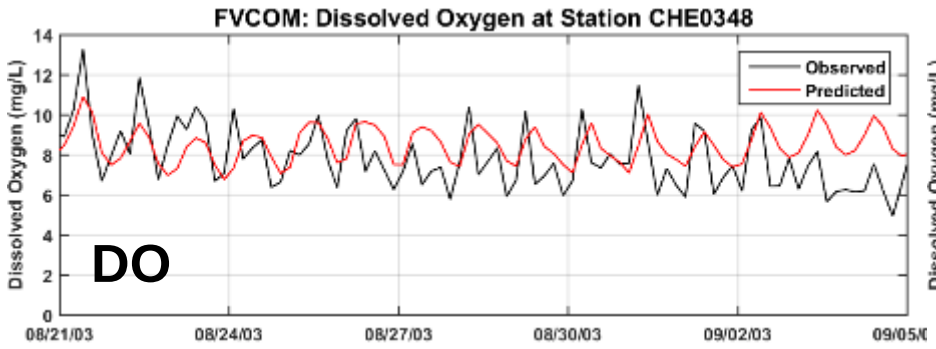


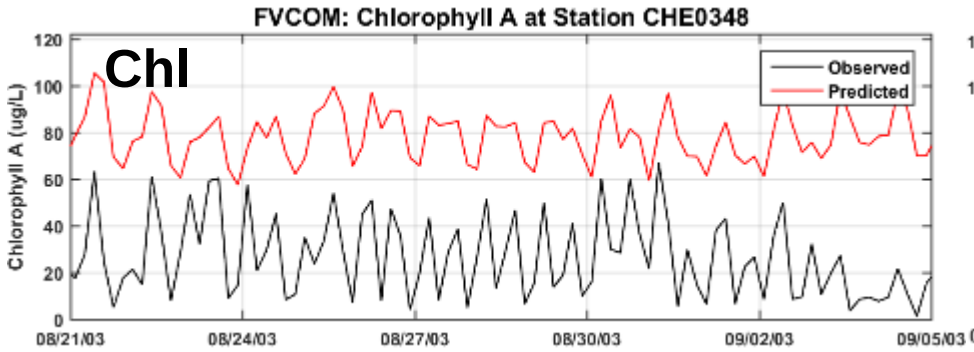
In upper Chester:

- FVCOM and SCHISM TSS are similar (low)
- SCHISM is low during dry summer
- ICM does better than old ICMp5.3.2, peaks are too high)

Daily variability in WQ in upper Chester

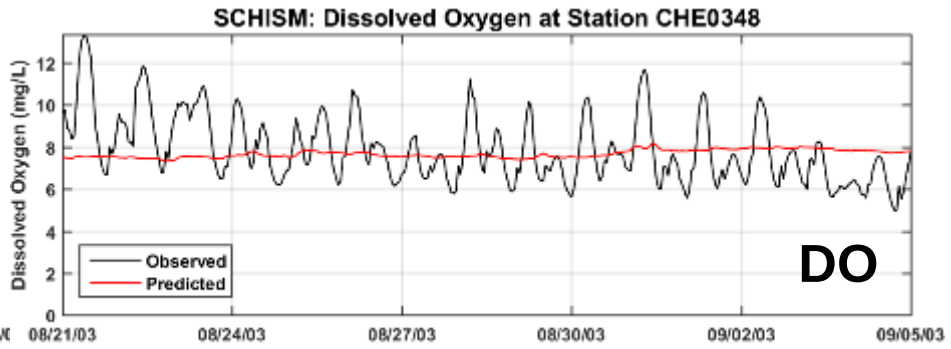
FVCOM

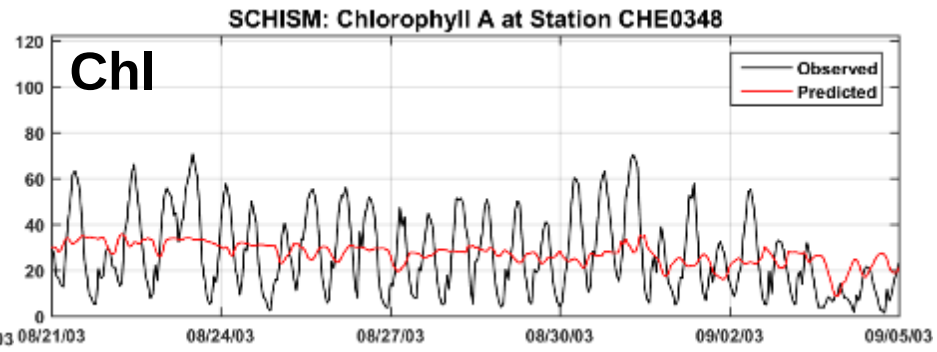




4 hourly output

SCHISM



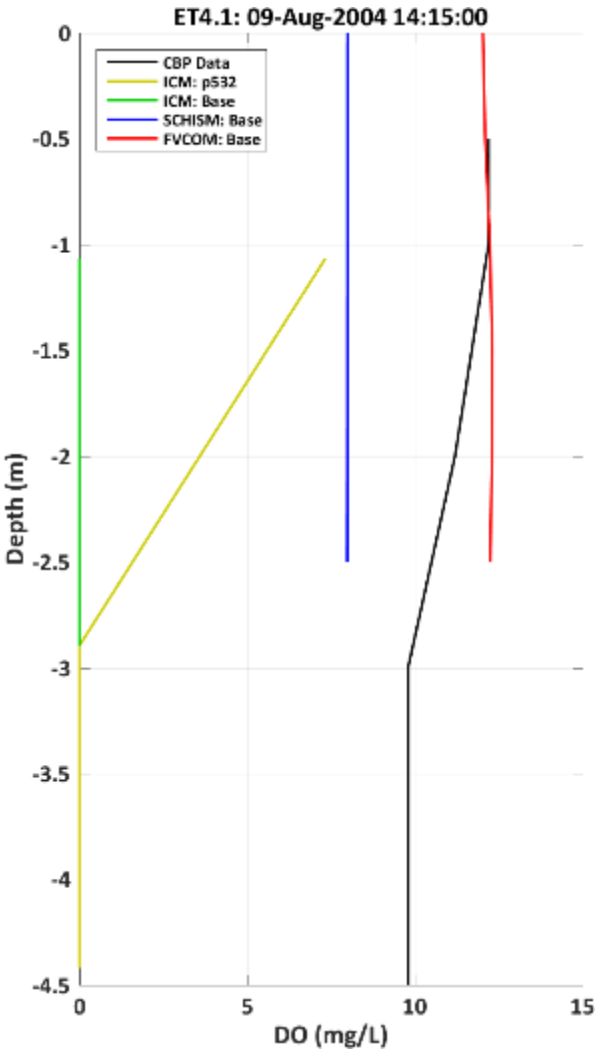


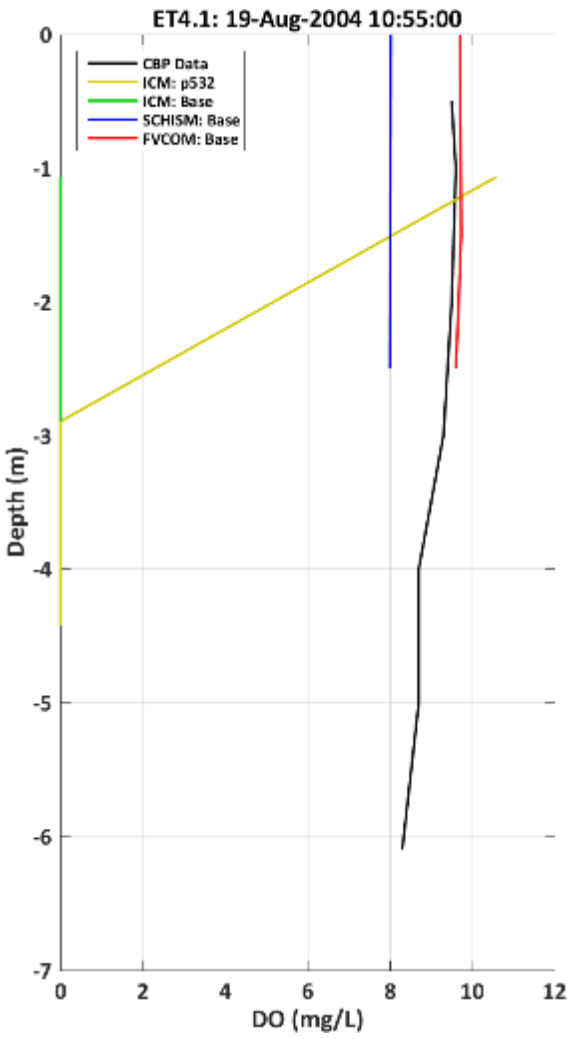
1 hourly output

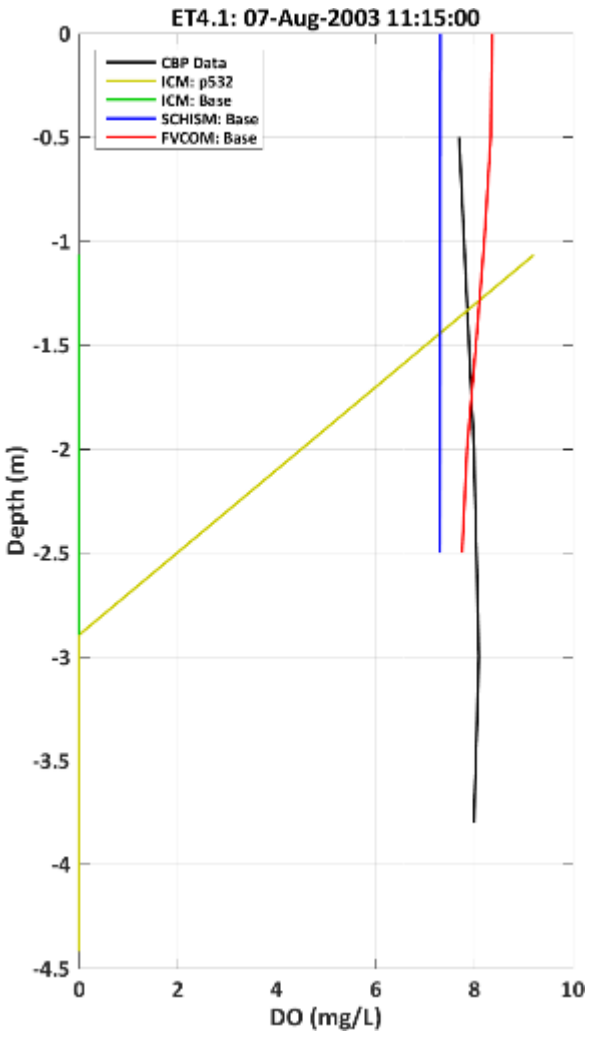
In upper Chester:

- FVCOM captures much more of the daily variability in DO and Chl than SCHISM
- (no hourly output available for ICM)

Vertical DO profiles: in August at ET4.1

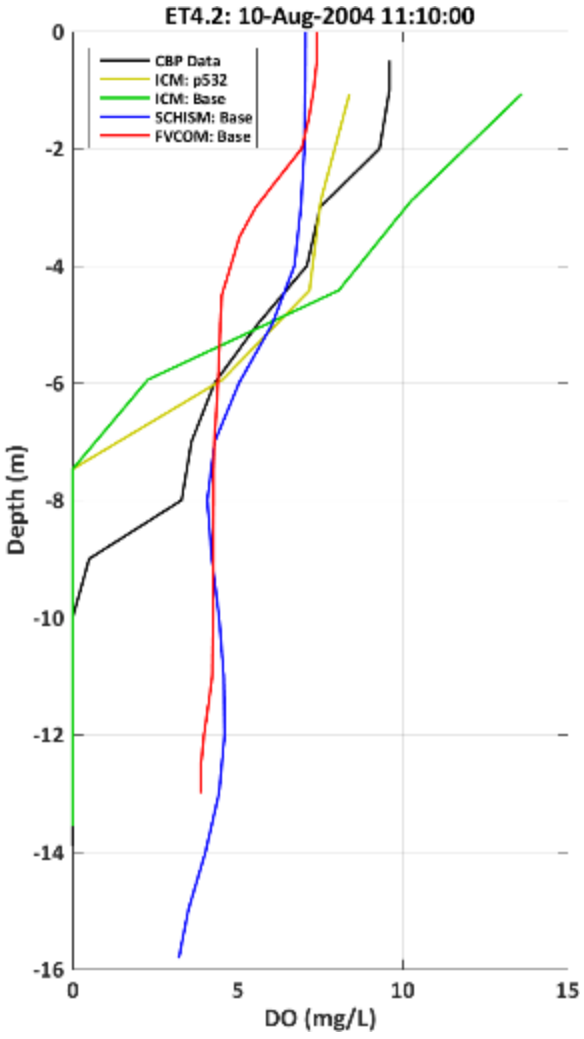


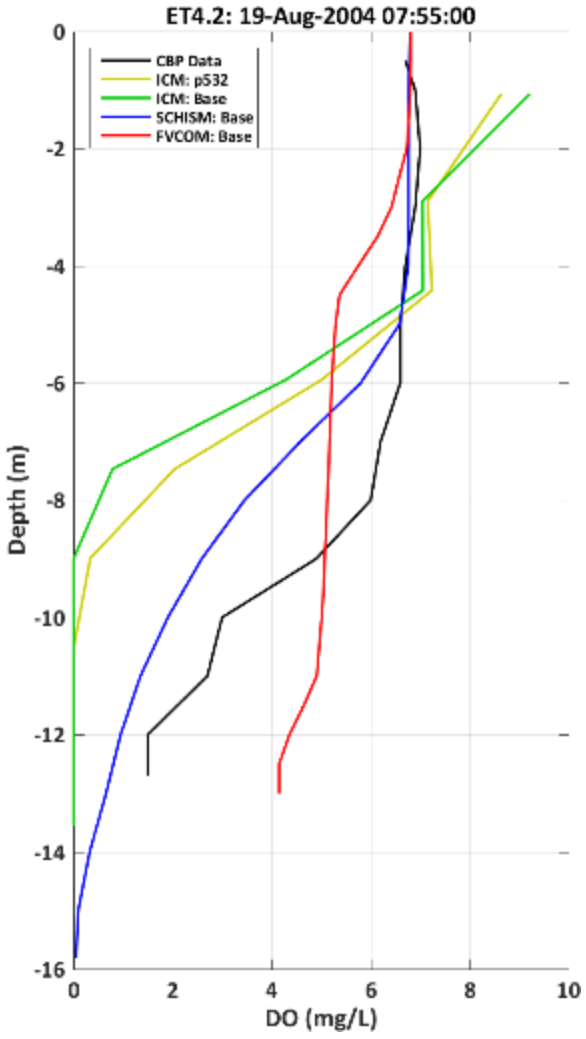


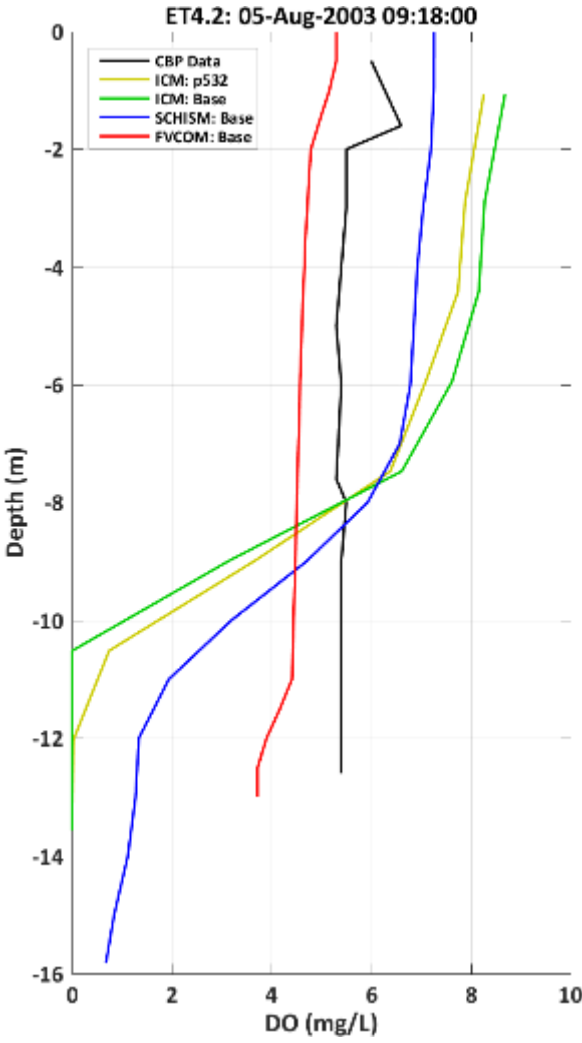


- Both ICMs are too anoxic at depth; ICMp5.3.2 is better at surface
- SCHISM and FVCOM do well (no DO stratification)

Vertical DO profiles: in August at ET4.2

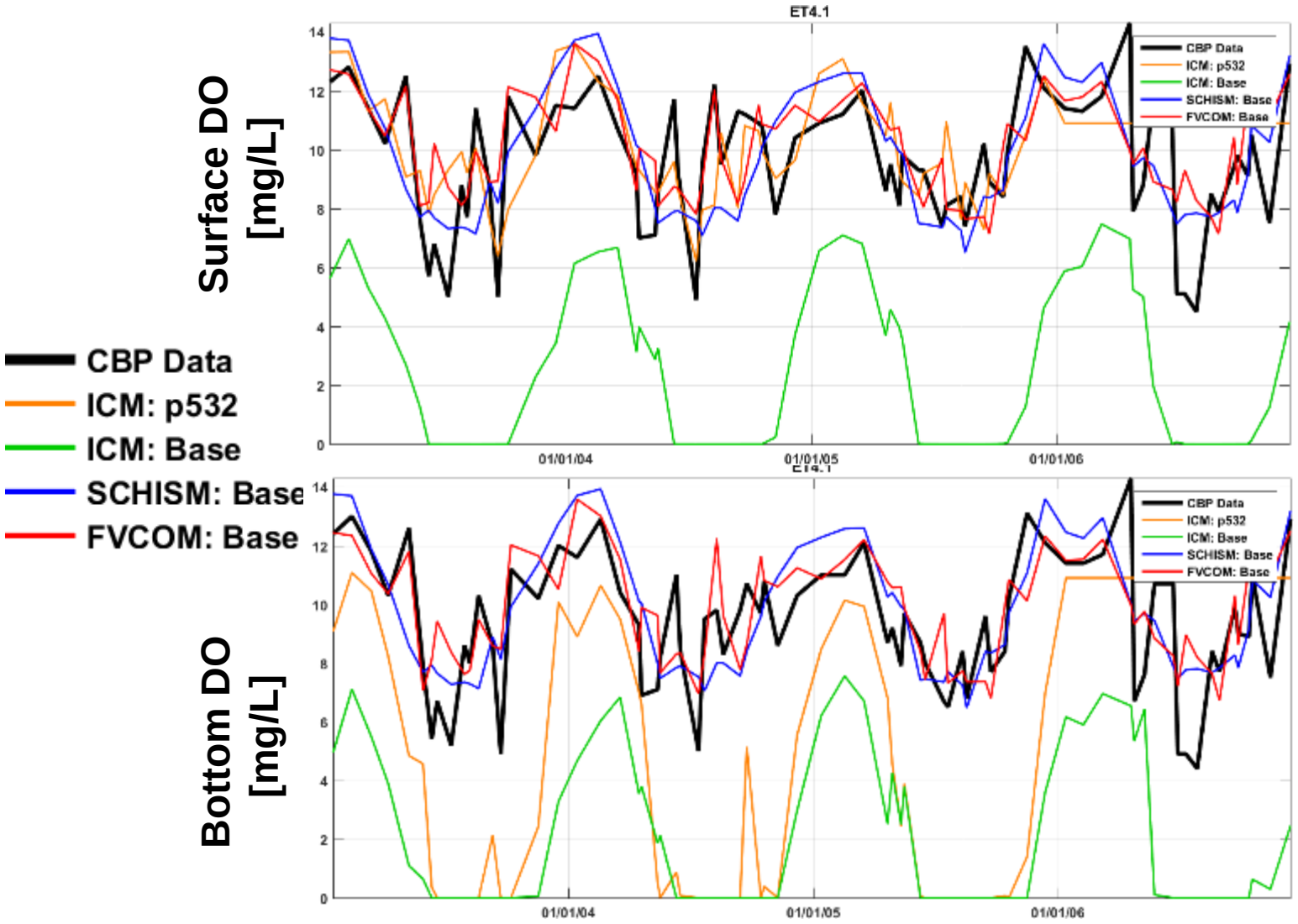






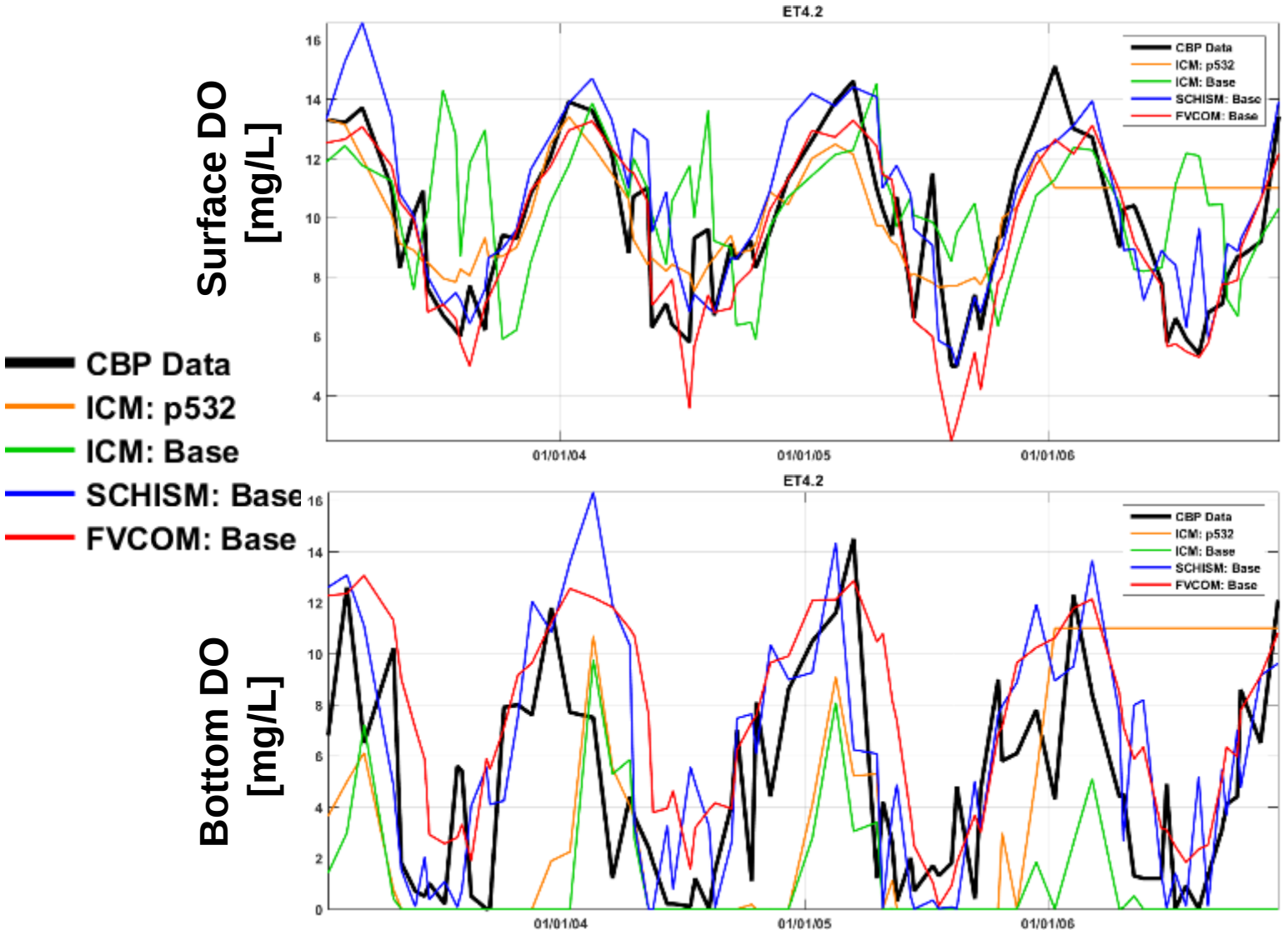
- Data show temporal variability in DO stratification; models do not
- Two ICMs are similar, and generally too hypoxic/anoxic

Vertical DO time series: at ET4.1



- All models (except for new ICM) simulate surface DO well at the surface
- Both ICMs underestimate bottom DO, showing significant anoxia/hypoxia

Vertical DO time series: at ET4.2



- All models (except for new ICM) simulate surface DO well at the surface
- Both ICMs underestimate bottom DO in Sept-March (anoxia in late fall)

Part 2: Water Quality (DO, Chl, TSS)

B. Sensitivity Experiments
(SCHISM only)

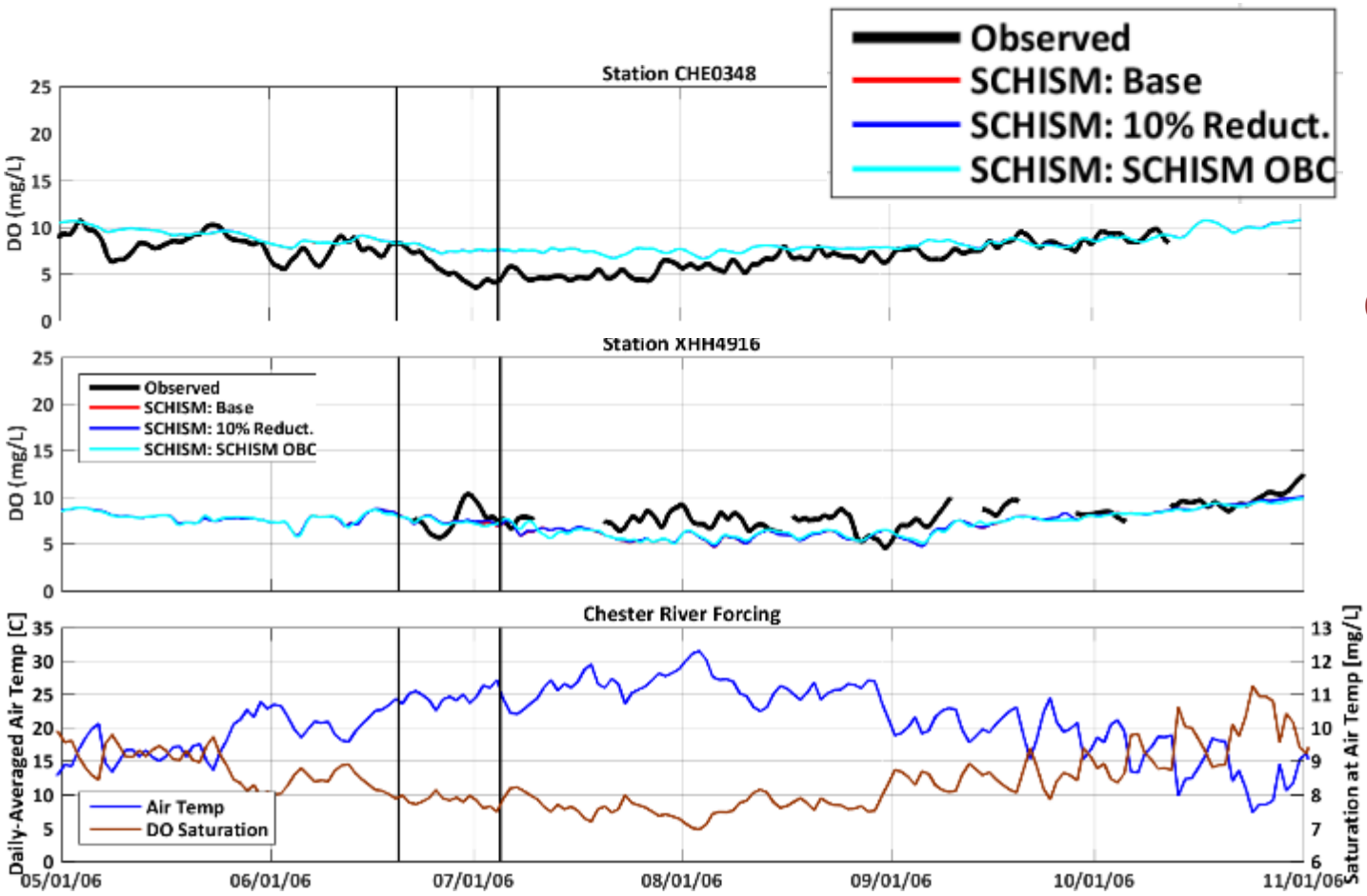
→ 10% decrease in inflow (freshwater+nutrient)

→ Change in T&S outer boundary conditions

Future:

- *change in WQ boundary conditions*
- *nutrient reduction scenarios*

DO – sensitivity results

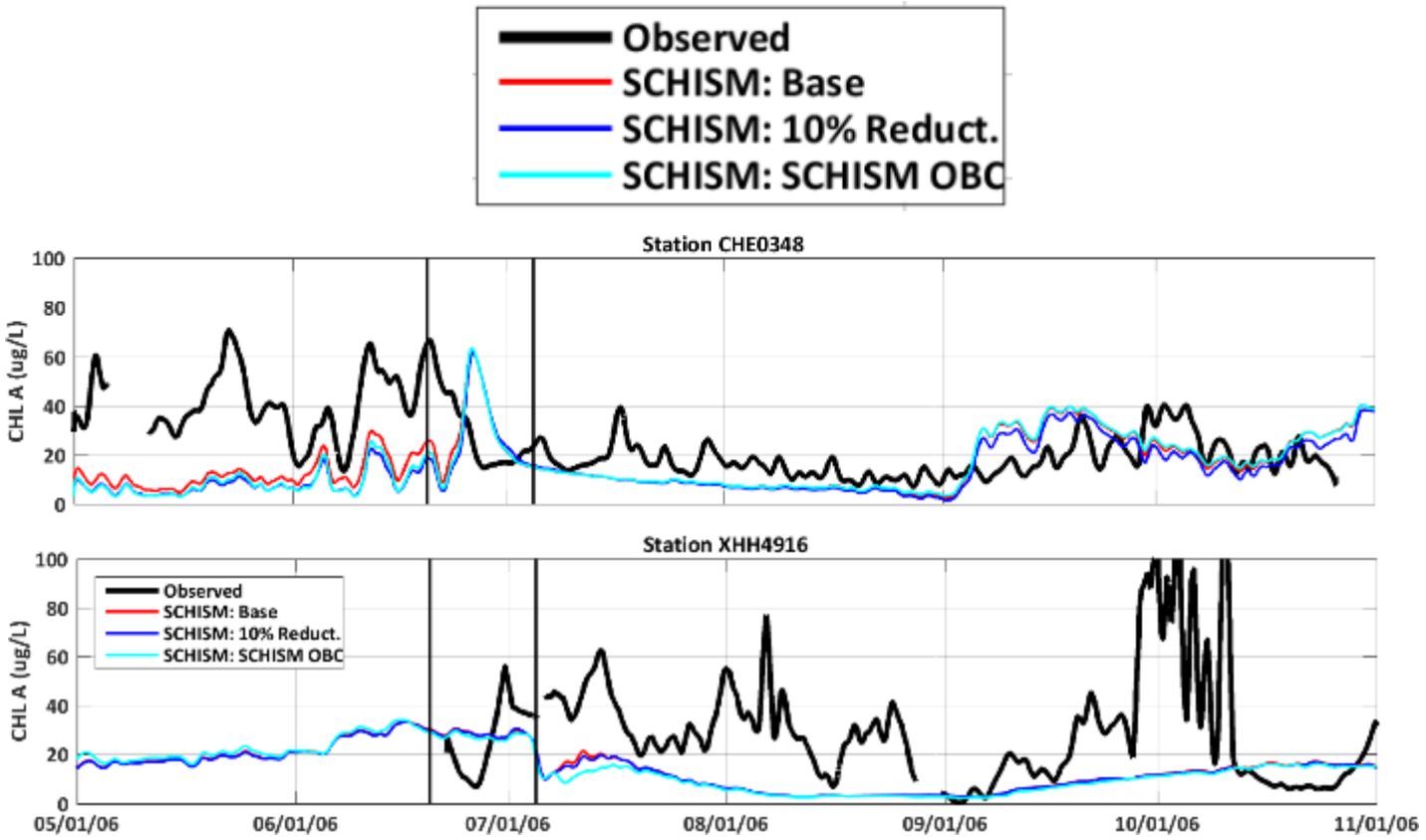


Sta. A upper Chester

Sta. C lower Chester

- DO is not sensitive to changes in T&S OBC or 10% inflow reduction

Chl – sensitivity results

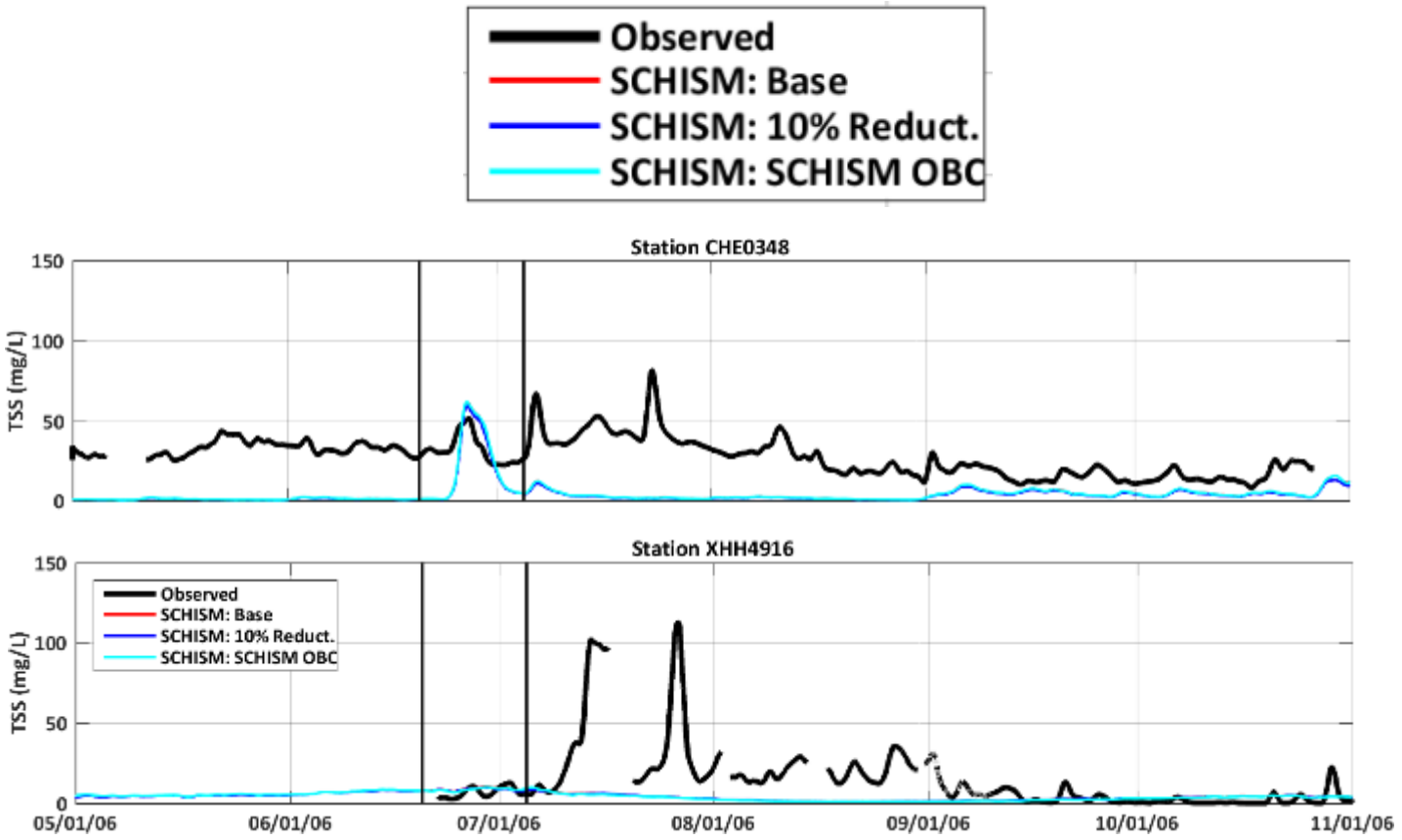


Sta. A upper Chester

Sta. C lower Chester

- Chl is not sensitive to changes in T&S OBC or 10% inflow reduction

TSM – sensitivity results



Sta. A upper Chester

Sta. C lower Chester

- TSS is not sensitive to changes in T&S OBC or 10% inflow reduction

But what about changes in water quality OBC?

Summary of Water Quality Results

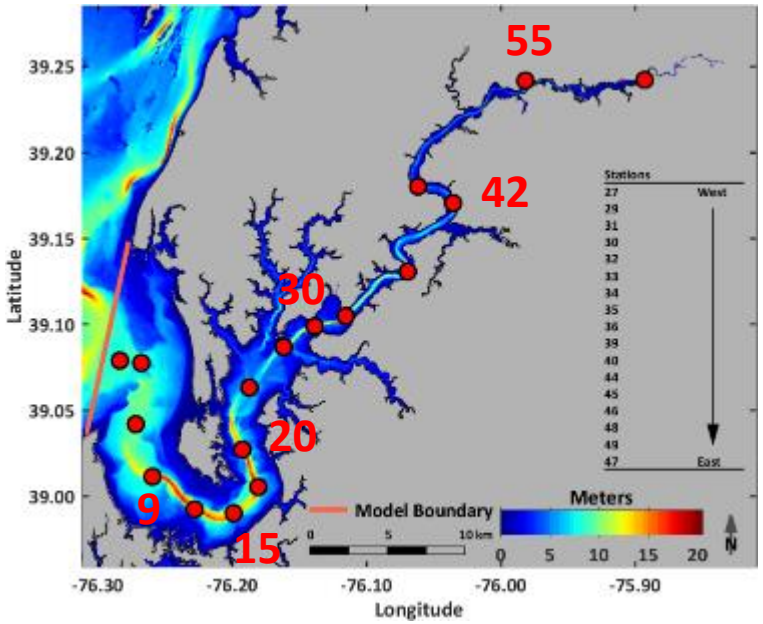
1. **Dissolved oxygen**
   - → FVCOM and SCHISM do quite well in reproducing mean DO
   - → SCHISM does not show diurnal variability as well as FVCOM
   - → Both ICM versions have issues

2. **Chlorophyll**
   - → FVCOM is high
   - → SCHISM is low in summer
   - → New ICM very low in upper Chester (despite anoxia)
   - → ICMp5.3.2 does well in upper Chester (high in summer)

3. **TSM**
   - → All models show too low background TSM
   - → New ICM has a reproduces background TSM; peaks are high

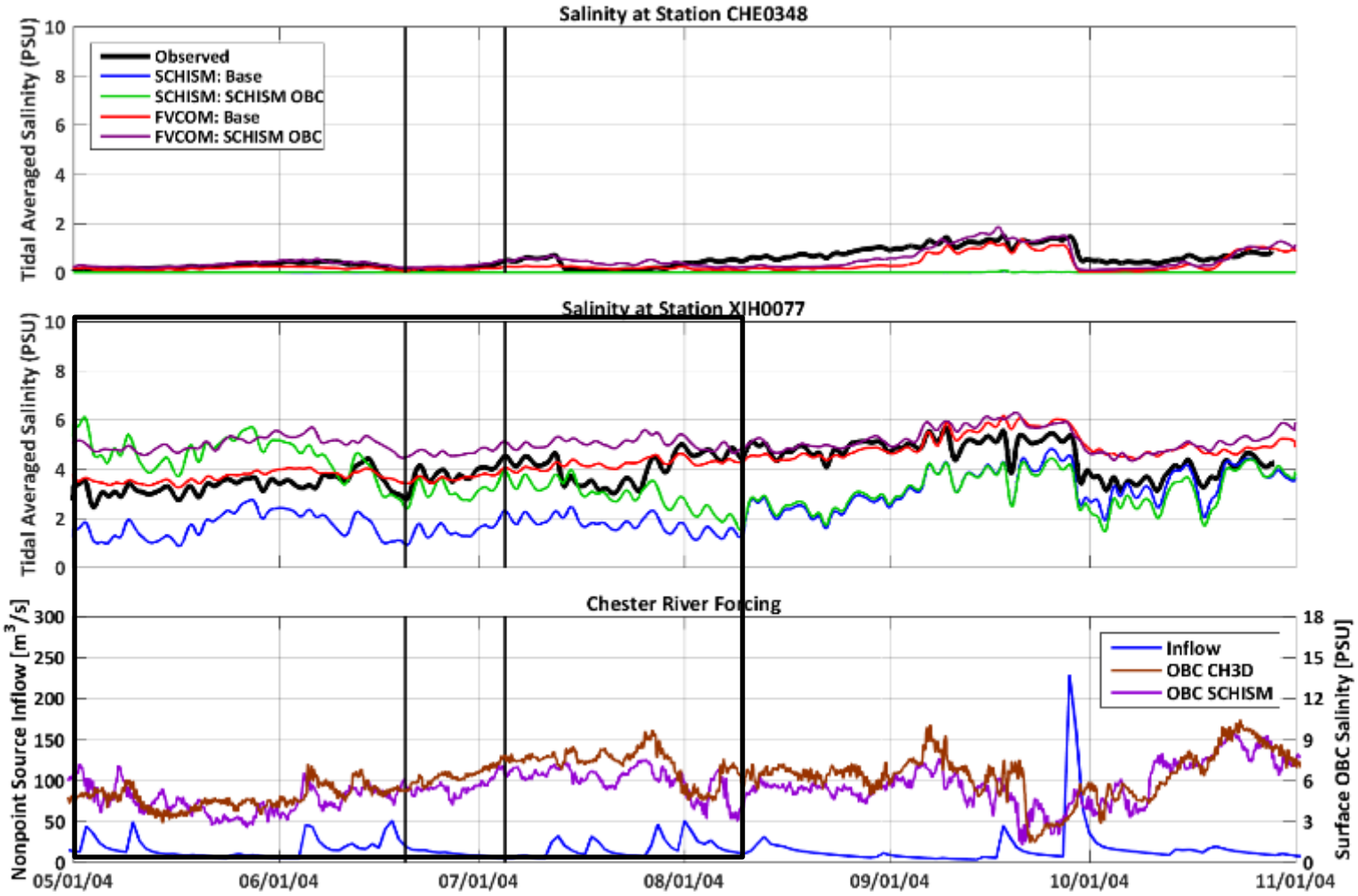
4. **Sensitivity experiments - SCHISM**
   - → 10% reduction of inflow and varying T&S OBC has small effect
   - → Largest on chlorophyll (smaller on DO and TSM)
   - → Changes in OBC and inflow produce effects of similar magnitude

Extra slides

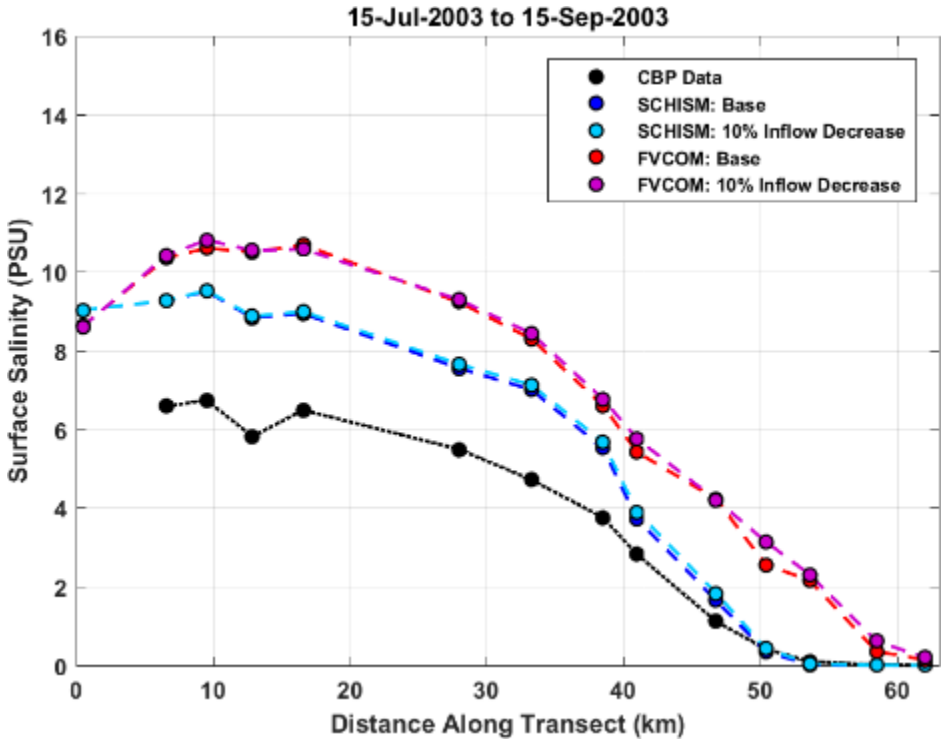


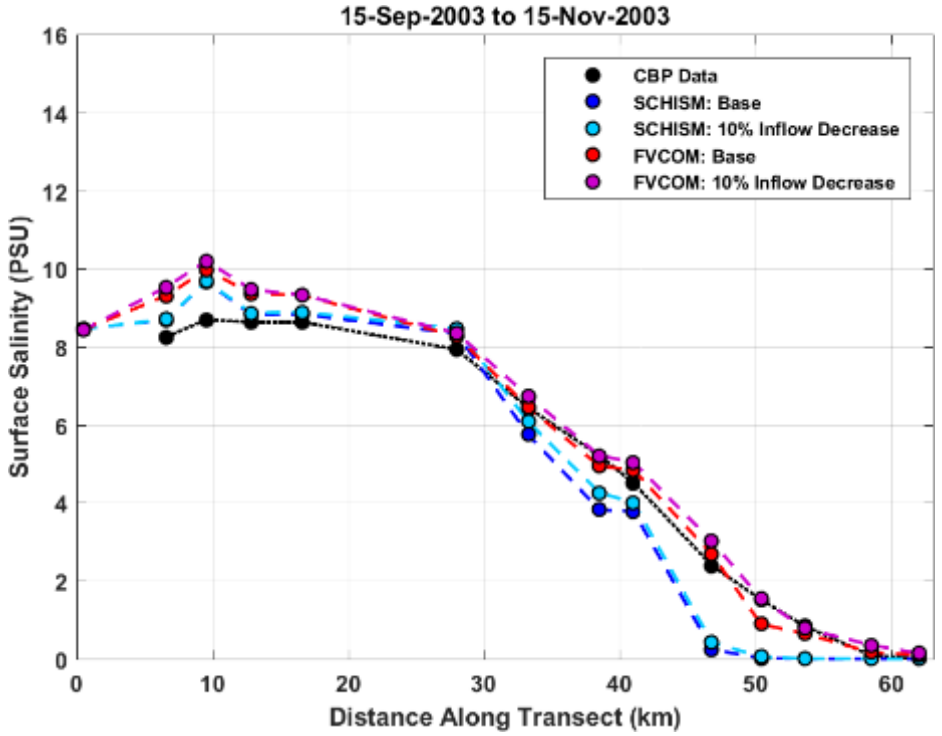
Effect of SCHISM open boundary conditions

- Large difference in model results between OBCs in May-July 2004
- Both FVCOM and SCHISM converge at same time (early August).
- Water surface elevation OBC?



Model results – salinity – 2003





Bay → upstream Bay → upstream

- Effect of 10% inflow decrease is small throughout Chester

Availability of Chester River data

WQ = semi-monthly cruise data in summer; otherwise monthly

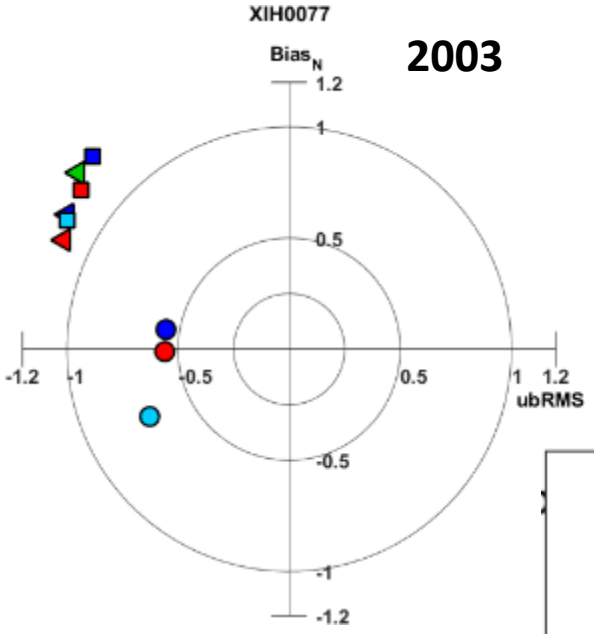
CMON = 15 minute data (April – October); fixed platform

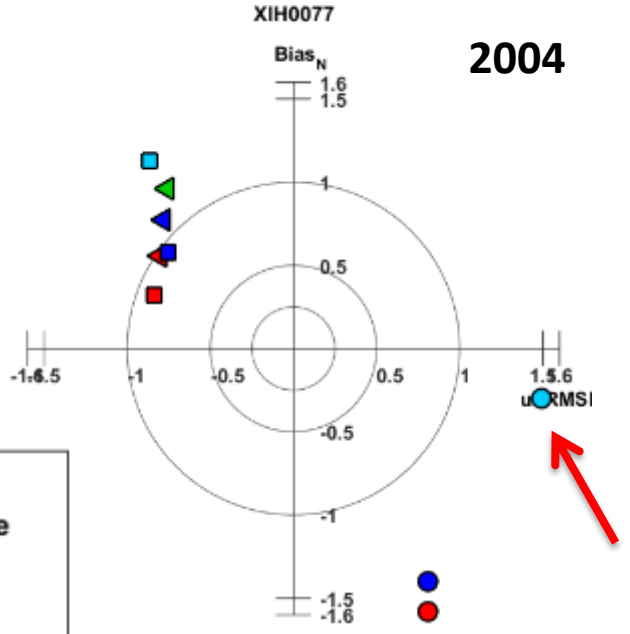
DFLO = ship visits stations weekly to monthly (May – August)

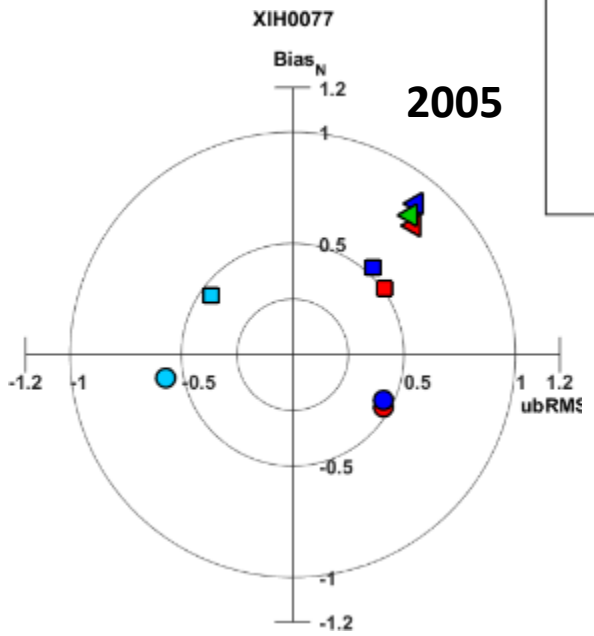
Orig. Station name	Years	Sta. Type	Used in time series	Used in along-river transects	Unused for now
ET4.1	2003-2010	WQ/DFLO		X	
ET4.2	2003-2010	WQ/DFLO		X	
XGG8251	2003-2010	WQ/DFLO			Kent Narr.
CHE0348	2003-2006	CMON/DFLO	X	X	
XIH0077	2003-2006	CMON/DFLO	X	X	
XHH3851	2005-2010	CMON/DFLO	X (Corsica)		
XHH4931	2006-2010	CMON/DFLO	X (Corsica)		
XHH4916	2006-2010	CMON/DFLO	X (Corsica)		
XHG8442	2009-2010	CMON/DFLO			Mouth
XHG2318	2009-2010	CMON/DFLO			Mouth
XGG8359	2007-2009	CMON			Kent Narr.
XGG8458	2007-2009	CMON			Kent Narr.
XHH5046	2005-2006	CMON			Corsica
XHG0859	2003-2006	DFLO		X	
XHG1579	2003-2006	DFLO		X	
GYI0001	2003-2006	DFLO			Grays Inn
XHG6496	2003-2006	DFLO			Langford Cr.
XHH6419	2003-2006	DFLO		X	
XHH4822	2003-2005	DFLO			Corsica
XGG9992	2003-2006	DFLO		X	
XIH3581	2003-2006	DFLO		X	
XHH7848	2003	DFLO		X	
XHH9362	2003	DFLO		X	
XIH1458	2003	DFLO		X	
XIH4495	2003	DFLO		X	

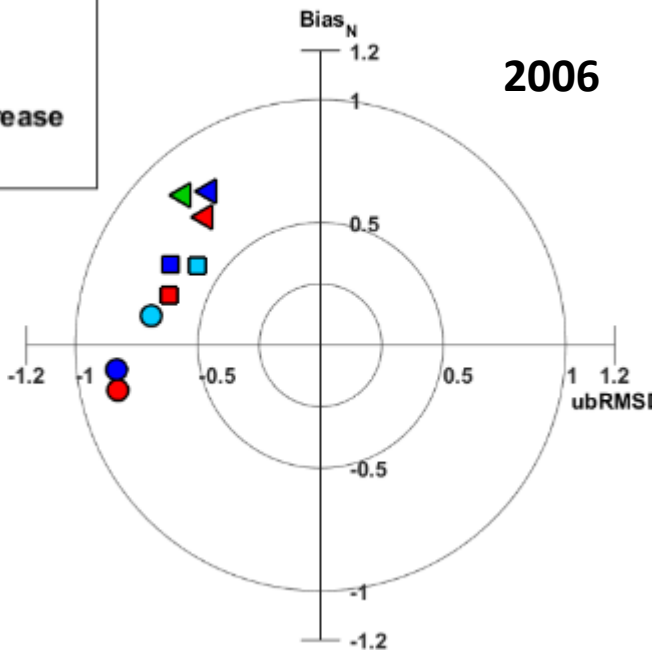
Effect of changing inflow and OBC on salinity: multiple years

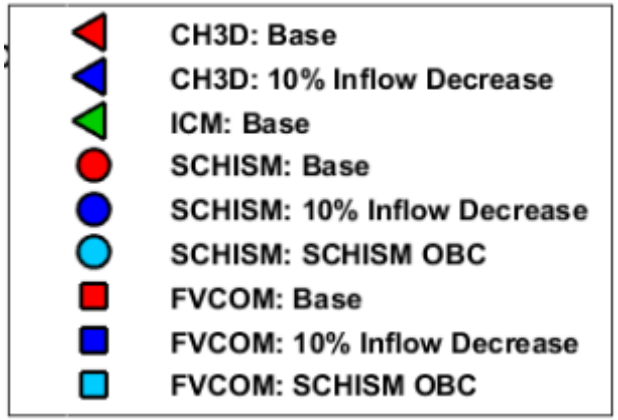
Station B











Similar results for all years (almost!)