A

Hydrodynamic Model Development and Calibration in Support of St. Marks River Rise MFL Evaluation

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1 Introduction and Objectives

The Northwest Florida Water Management District (District) is developing minimum flows and levels (MFLs) for the St. Marks River Rise, Wakulla Spring, and Sally Ward Spring. The MFLs will address protection of water resources affected by reduced spring flows, including those in the downstream freshwater and estuarine reaches of the Wakulla and St. Marks rivers.

As part of this effort, modeling tools have been developed to evaluate and predict the effects of various spring flow reduction scenarios on selected water resource values. These models include a mechanistic model for simulation of the hydrodynamic responses (salinity, temperature, water velocities, water surface elevation) within the combined St. Marks and Wakulla rivers system to aid in determination of the St. Marks River and Wakulla River MFLs. For each of the modeling efforts, specific data are needed for model development and implementation.

The data collection effort as provided in the Hydrodynamic Model Sampling Plan (Janicki Environmental, 2015a) continued through August 2017. Data resulting from this monitoring effort were used to develop and calibrate a hydrodynamic model of the tidal portions of the rivers, with the model domain extending from the US 98 crossings of both the St. Marks and Wakulla rivers to the mouth of the St. Marks River in Apalachee Bay and offshore into the Gulf of Mexico (Figure 1).

This current document provides the results of a series of tasks, part of Task Oder (TO) #3 directed at development and calibration of the hydrodynamic model to be used for potential MFL scenario evaluation. The tasks are as follows:

- Develop the hydrodynamic model grid system;
- Develop input datasets for the Environmental Fluid Dynamics Code (EFDC) hydrodynamic model calibration;
- Develop and calibrate the EFDC hydrodynamic model; and
- Perform sensitivity analysis and implement preliminary spring flow reduction scenarios during the calibration period to guide future potential MFL scenarios definition.

Following this introduction, this report consists of four sections addressing these tasks. Section 2 presents the development of the model, including the selection of and a general description of the EFDC hydrodynamic model utilized for this project, the model grid system, the data sources used for model inputs, and the period of the calibration simulation. Section 3 presents the model calibration including the data used for comparison with model output along with graphical and statistical comparisons of the model versus measured data. Section 4 presents the results of application of the of the calibrated model for a sensitivity analysis of model responsiveness to important parameterizations, and the results of application of the calibrated model during the calibration period under initial spring flow reduction scenarios. Section 5 summarizes the results of the model development and calibration.

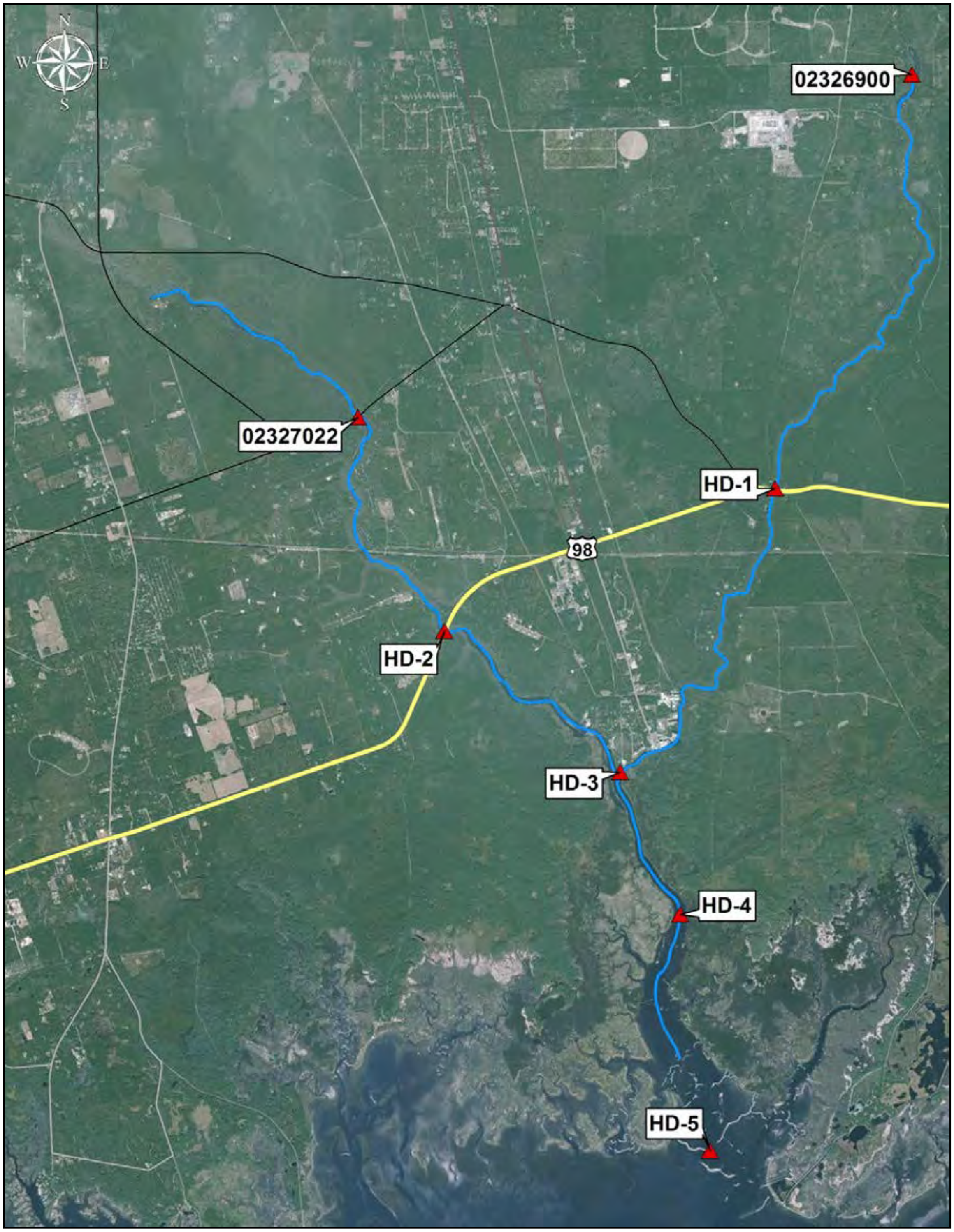

Figure 1. **Locations of St. Marks/Wakulla hydrodynamic model study area. Upstream extents of the model domain are the US98 crossings of the St. Marks River and Wakulla River. Downstream extent of the model domain is approximately 3 km offshore of the river mouth. Locations of continuous recorders (HD) and USGS stream flow gages used in model development.**

2 Hydrodynamic Model Development

This section provides a detailed description of the development of the hydrodynamic model for the St. Marks and Wakulla rivers. This includes the selection and general description of the EFDC hydrodynamic model utilized for this project, the model grid system, the period of the calibration simulation, and the data sources used for model boundary condition inputs.

2.1 Model Selection

Our experience with the Environmental Fluid Dynamics Code (EFDC) modeling suite and the use of this suite to evaluate MFLs in other Florida west coast regions (Suwannee River Water Management District, Southwest Florida Water Management District) is a strong recommendation for this model. This subsection provides brief summaries of several hydrodynamic models and compares them to provide additional support to the selection of the EFDC model for this effort.

The primary hydrodynamic models considered for this application included the following:

- Princeton Ocean Model (POM),
- Estuarine Coastal and Ocean Model with Sediment Dynamics (ECOMSED) ,
- Curvilinear Hydrodynamics in 3-Dimensions (CH3D),
- EFDC, and
- Unstructured Grid Finite Volume Coastal Ocean Model (FVCOM).

Hydrodynamic models utilizing all of these packages have been applied to estuarine systems, including both rivers and embayments. The EFDC model is part of the EPA's development of models for use in establishing Numeric Nutrient Criteria, in addition to having already been applied to numerous river estuaries in Florida.

Princeton Ocean Model (POM):
http://www.ccpo.odu.edu/POMWEB/
POM is a three-dimensional (3-D) time-dependent hydrodynamic model with the following principal attributes:

- solution of full momentum, continuity, temperature, salinity and density equations;
- sigma coordinate representation of vertical component;
- curvilinear orthogonal coordinate system in the horizontal;
- imbedded second-order turbulence closure scheme to represent turbulence mixing;
- 2-D/3-D mode-splitting solution scheme where the full external solution is in two dimensions and an internal mode to solve for the vertical variations;
- full simulation of the density (baroclinic) terms in 3-D (salinity and temperature);
- full simulation of heat exchange and internal response (temperature); and
- open and available source code.

POM has been utilized in numerous applications throughout the US and has been the base code for numerous modifications that have become widely used public domain hydrodynamic models. While the base POM model is still fully supported and maintained, numerous versions have been created and renamed. These models have been built upon the POM framework and subsequent additional attributes, linkages, and capabilities added to improve their applicability and performance in coastal systems.

Estuarine Coastal and Ocean Model with Sediment Dynamics (ECOMSED):
Maintained by HDR, http://www.hdrinc.com for contact information
ECOMSED is a 3-D hydrodynamic model originally developed by HydroQual, Inc., now a part of HDR. The model has the following principal attributes:

- solution of full momentum, continuity, temperature, salinity and density equations;
- sigma coordinate representation of vertical component;
- curvilinear orthogonal coordinate system in the horizontal;
- imbedded second-order turbulence closure scheme to represent turbulence mixing;
- 2-D/3-D mode-splitting solution scheme where the full external solution is in two dimensions and an internal mode to solve for the vertical variations;
- full simulation of the density (baroclinic) terms in 3-D (salinity and temperature);
- full simulation of heat exchange and internal response (temperature); and
- open and available source code.

The development of ECOMSED has its origins in the mid 1980s with the creation of the POM and its version for shallow water environments – rivers, bays, estuaries and the coastal ocean and reservoirs and lakes - named ECOM. In the mid 1990s, concepts for cohesive sediment re-suspension, settling and consolidation were incorporated within the ECOM modeling framework. During the last several years, ECOMSED was enhanced to include generalized open boundary conditions, tracers, better bottom shear stresses through a sub-model for bottom boundary layer physics, surface wave models, non-cohesive sediment transport, and dissolved and sediment-bound tracer capabilities.

ECOMSED has a number of specific attributes that are useful for estuarine river modeling, including:

- thin wall barrier to represent narrow barriers such as causeways without impacting grid resolution;
- simulation of connecting structures such as culverts;
- spatially varying meteorological forcing (i.e., wind fields);
- wave model sub-component linkage (SWAN or Donnelin Model);
- efficient parallelization on standard personal computing environment; and
- fully tested sub-grid linkage to water quality model (allowing simulation of water quality conditions within only a portion of the hydrodynamic domain).

Environmental Fluid Dynamics Code (EFDC):
https://www.epa.gov/exposure-assessment-models/environment-fluid-dynamics-code-efdc-download-page
EFDC is a 3-D time-dependent hydrodynamic model with the following principal attributes:

- solution of full momentum, continuity, temperature, salinity and density equations;
- option for either sigma coordinate representation of vertical component or generalized vertical coordinate option (a laterally constrained localized [LCL] sigma transform, which can be mixed with standard sigma vertical grids on a sub-domain basis in a single model);
- curvilinear orthogonal coordinate system in the horizontal;
- embedded second-order turbulence closure scheme to represent turbulence mixing;
- 2-D/3-D mode-splitting solution scheme where the full external solution is in two dimensions and an internal mode to solve for the vertical variations;
- full simulation of the density (baroclinic) terms in 3-D (salinity and temperature);
- full simulation of heat exchange and internal response (temperature); and
- open and available source code.

While the EFDC model is not as directly tied to the POM model development as ECOMSED, it is nearly identical in its overall representation of the model domain and its solution schemes and techniques. EFDC has integrated links for simulation of sediment transport, a fully integrated water quality component, and numerous biological component linkages.

EFDC has a number of specific attributes that are useful for the application for estuarine river modeling, including:

- thin wall barrier to represent narrow barriers such as causeways without impacting grid resolution;
- simulation of connecting structures such as culverts;
- spatially varying meteorological forcing (i.e., wind fields);
- wave model sub-component linkage (SWAN or STWAVE); and
- efficient parallelization on standard personal computing environment.

Curvilinear Hydrodynamic Model in 3-Dimensions (CH3D):
http://ch3d.coastal.ufl.edu/
CH3D is a 3-D hydrodynamic model with the following principal attributes:

- solution of full momentum, continuity, temperature, salinity and density equations;
- sigma coordinate representation of vertical component;
- curvilinear non-orthogonal coordinate system in the horizontal;
- imbedded second-order turbulence closure scheme to represent turbulence mixing;

- 2-D/3-D mode-splitting solution scheme where the full external solution is in two dimensions and an internal mode to solve for the vertical variations;
- full simulation of the density (baroclinic) terms in 3-D (salinity and temperature);
- full simulation of heat exchange and internal response (temperature); and
- open and available source code.

While the CH3D model is not as directly tied to the POM model development as ECOMSED, it is nearly identical in its overall representation of the model domain and its solution schemes and techniques. The one key difference is that CH3D is a non-orthogonal grid model which allows some additional flexibility in terms of representation of shorelines and geometry. CH3D also has integrated links for simulation of sediment transport, a fully integrated water quality component, and numerous biological component linkages, although some of these attributes are not directly available as open source code versions.

CH3D has a number of specific attributes that are useful for estuarine river modeling, including:

- thin wall barrier to represent narrow barriers such as causeways without impacting grid resolution;
- spatially varying meteorological forcing (i.e., wind fields);
- wave model sub-component linkage (SWAN or REFDIF); and
- efficient parallelization on standard personal computing environment.

Unstructured Grid Finite Volume Coastal Ocean Model (FVCOM):
http://fvcom.smast.umassd.edu/FVCOM/index.html
FVCOM is a 3-D hydrodynamic model with the following principal attributes:

- sigma coordinate representation of vertical component;
- 2-D/3-D mode-splitting solution scheme where the full external solution is in two dimensions and an internal mode to solve for the vertical variations;
- unstructured grid, finite volume;
- solution of full momentum, continuity, temperature, salinity and density equations;
- utilizes General Ocean Turbulent Model (GOTM) developed by Burchard's research group in Germany (Burchard, 2002) to provide optional vertical turbulent closure schemes;
- full simulation of the density (baroclinic) terms in 3-D (salinity and temperature);
- full simulation of heat exchange and internal response (temperature); and
- open and available source code.

While the other models presented are structured grid finite difference models, the FVCOM is the only unstructured grid model considered for this project. The key aspect of unstructured grid modeling is the flexibility and resolution obtainable with the grid representation of the overall system. FVCOM has integrated links for sediment transport, water quality, biological modeling, and waves. One limitation on the FVCOM model is that its use is limited to "…use in non-commercial academic research and education", making it unsuitable for use in this effort.

The major advantage of the FVCOM model as compared to the other structured grid models is the degree to which the geometric conditions in the system can be simulated, and the flexibility in the application of finer grids within targeted areas of the system.

Selected Hydrodynamic Model

Table 1 shows key attributes needed for the hydrodynamic modeling of the tidal St. Marks River and Wakulla River. For each attribute, the model is identified to either have or not have sufficient capability in that area. Overall, the models' capabilities are similar and the determination of the model to be utilized will reflect minor advantages. It is important to recall that use of the model in development of several other MFLs along Florida's west coast, and familiarity of the project team with the model being utilized, are strong recommendations for use of the EFDC model.

Table 1. Hydrodynamic model key attributes for comparison.

Attribute	POM	ECOMSED	EFDC	CH3D	FVCOM
Full 3-D Momentum, Continuity, Density, Temperature, Salinity	√	√	√	√	√
Full Turbulence	√	√	√	√	√
Flexible Grid	√	√	√	√	√√
Representation of Structures		√	√		
Spatially Variant Wind Field	√	√	√	√	√
Wave Sub-Model		√	√	√	√
Open/available Source Code	√	√	√		√
Efficient Parallelization		√	√	√	√
Water Quality Linkage		√	√	√	√

Examination of the attributes shown in Table 1 indicates that both ECOMSED and EFDC have very similar capabilities for this project. Given the appropriateness of the EFDC model, the use of this model in several other west Florida tidal rivers, and our familiarity with it, the EFDC model was selected for this calibration effort.

2.2 Model Description

The EFDC model used in this project is a general purpose modeling package for simulating two- and three-dimensional flow, transport, and biogeochemical processes in surface water systems, including rivers, lakes, estuaries, reservoirs, wetlands, and nearshore to shelf-scale coastal regions. The EFDC model was developed by Dr. John Hamrick at the Virginia Institute of Marine Science and is considered public domain software (Hamrick 1992a, 1992b). EFDC is currently supported by the U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD), EPA Region 4, and EPA Headquarters. A link to the EPA website for the EFDC model is https://www.epa.gov/exposure-assessment-models/environment-fluid-dynamics-code-efdc-download-page. Additionally, the Florida Department of Environmental Protection (FDEP) and the Water Management Districts (WMDs) throughout the state have used this model extensively. Specific examples of FDEP and the WMD applications of EFDC include the Indian River Lagoon [St. Johns River Water Management District (SJRWMD)], tidal portions of the St. Johns River (SJRWMD), Florida Bay [South Florida Water Management District (SFWMD)], tidal Caloosahatchee River (FDEP), Pensacola and Escambia Bay (FDEP) , and the tidal Suwannee River (USGS for the SRWMD). The EFDC hydrodynamic model has recently been used to support development of several MFLs throughout Florida as well, including Cow Pen Slough/Dona and Roberts Bay (Applied Technology and Management and Janicki Environmental, 2007), the Econfina River (Janicki Environmental, 2015b), the Aucilla River (Applied Technology and Management, 2015), and the Silver River (Kaplan and Suczy, 2016), and is currently being used in development of the MFL for the Steinhatchee River (Suwannee River Water Management District, 2017).

The physics of the EFDC model, and many aspects of the computational scheme, are equivalent to the widely used Blumberg-Mellor (1987) model (the POM). The EFDC model solves the three-dimensional, vertically hydrostatic, free surface, turbulent-averaged equations of motions for a variable density fluid. Dynamically coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity, and temperature are also solved. The two turbulence parameter transport equations implement the Mellor-Yamada level 2.5 turbulence closure scheme. The EFDC model uses a stretched or sigma vertical coordinate and curvilinear orthogonal horizontal coordinates.

The numerical scheme employed in EFDC to solve the equations of motion uses second-order accurate spatial finite differencing on a staggered or C grid. The model's time integration employs a second-order accurate three-time level, finite difference scheme with an internal-external mode splitting procedure to separate the internal shear or baroclinic mode from the external free surface gravity wave or barotropic mode. The external mode solution is semi-implicit and simultaneously computes the two-dimensional surface elevation field by a preconditioned conjugate gradient procedure. The external solution is completed by the calculation of the depth-averaged barotropic velocities using the new surface elevation field. The model's semi-implicit external solution allows large time steps that are constrained only by the stability criteria of the explicit central difference or higher order upwind advection scheme used for the nonlinear accelerations. Horizontal boundary conditions for the external mode solution include options for simultaneously specifying the surface elevation only, the characteristic of an incoming wave, free radiation of an outgoing wave or the normal volumetric flux on arbitrary portions of the boundary.

2.3 Model Grid and Bathymetry

The first task of the hydrodynamic model development is the definition of the model extent, or spatial model domain. This is achieved through the development of the model grid. For the St. Marks/Wakulla model grid system, the representation of the shoreline used was based on bathymetry data collected by another District contractor (Wantman Group, Inc., 2016) in early August 2016, combined with aerial photography of the area.

The river bathymetry data collection extended from the mouth of the river (near HD-5 in Figure 1) upstream approximately 2 km past the US 98 bridge crossings on both rivers. The vertical reference of the bathymetry data collection was the North American Vertical Datum of 1988 (NAVD88), with vertical accuracy standard of $\pm$0.20 ft. (Wantman Group, Inc., 2016). Offshore of the mouth of the river, bathymetry data were taken from the Florida Shelf Habitat (FLaSH) mapping study (Robbins et al., 2007). This was a multi-agency effort that created a compilation dataset of available bathymetry data from the Florida coast to the edge of the Florida shelf. This coverage is a bathymetry point file that was used to create the elevations for the model grid cells offshore in the Gulf of Mexico. Bottom elevations were converted from the vertical datum of the coverage [mean lower low water (*MLLW*)] to NAVD88. For the offshore bathymetric conditions in the final model grid, adjustments were made for the model to allow progression of the tidal wave to the mouth and facilitate boundary matching at the mouth. Grid cell depths were interpolated from point bathymetry data falling within each grid cell, and for those cells without bathymetric data points, interpolation between nearby cells with bathymetry data points was used, along with best professional judgment, to complete the grid cell bathymetry.

The model grid, provided in Figures 2-4, contains 2,416 horizontal cells and 6 vertical layers for each horizontal cell, with minimum horizontal dimensions on the order of 10x30 m and maximum horizontal dimensions on the order of 300x300 m. Bottom elevations range from -0.20 m to -6.74 m (NAVD88). Increases in both horizontal and vertical resolution are possible, but past experience has shown these scales of resolution for estuarine rivers along the northwestern Florida coast are appropriate for resolving the important responses in water movement and salinity necessary to make informed decisions concerning freshwater inflows and resultant salinity distributions. It is possible to develop a more highly refined horizontal and vertical grid system, to the limit of the bathymetric data collection, although the spatial distribution of the collected data still demand interpolation of depths for those locations where depth data were not collected. Our experience has found that the computational time required to run more highly resolved grid systems can become prohibitive without providing additional information into system responses, and that sound decision-making can result based on the information provided by model output at these spatial scales.

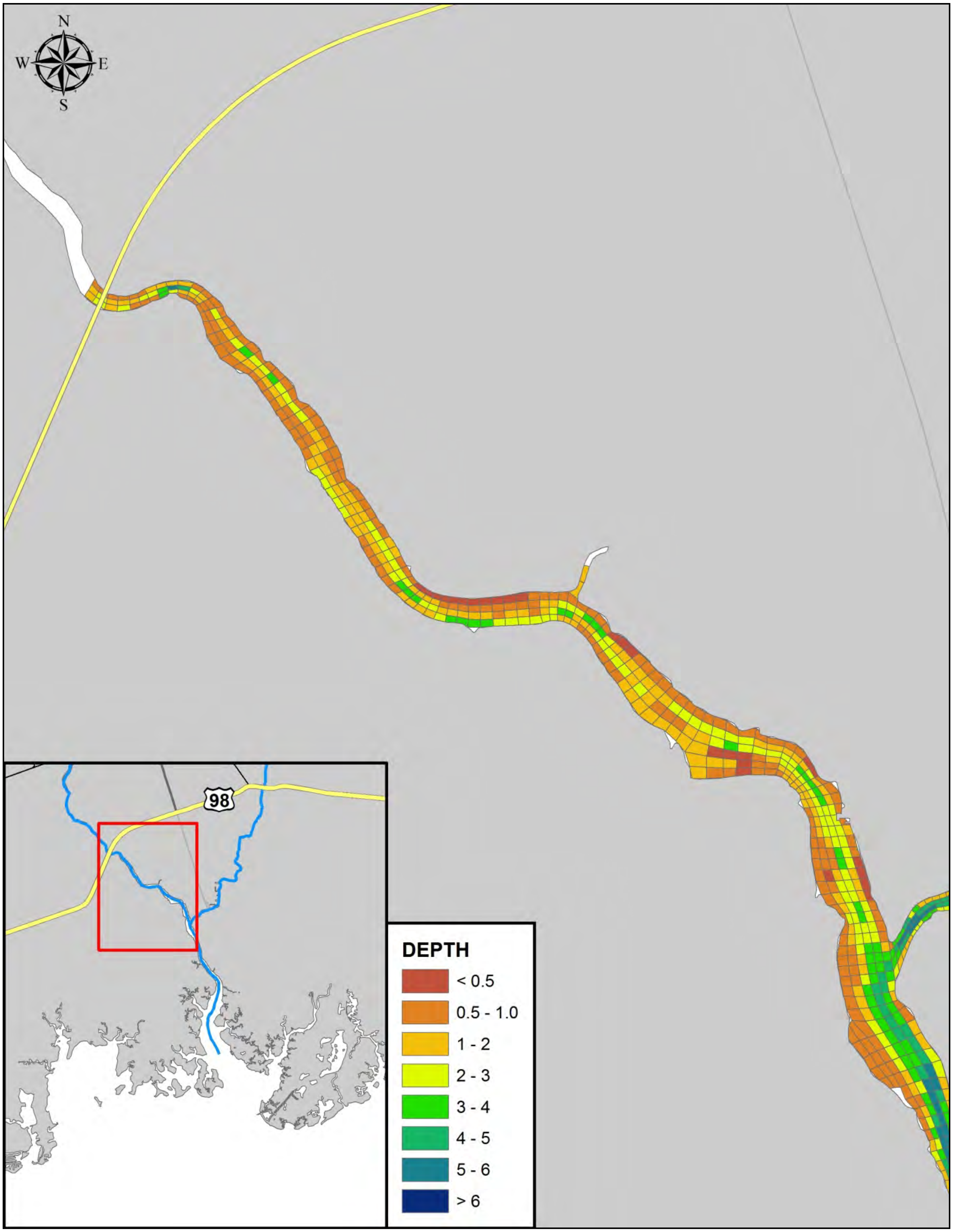

Figure 2. Model grid and bathymetry for the Wakulla River portion of the model domain. Vertical reference is NAVD88, vertical (depth) units are meters.

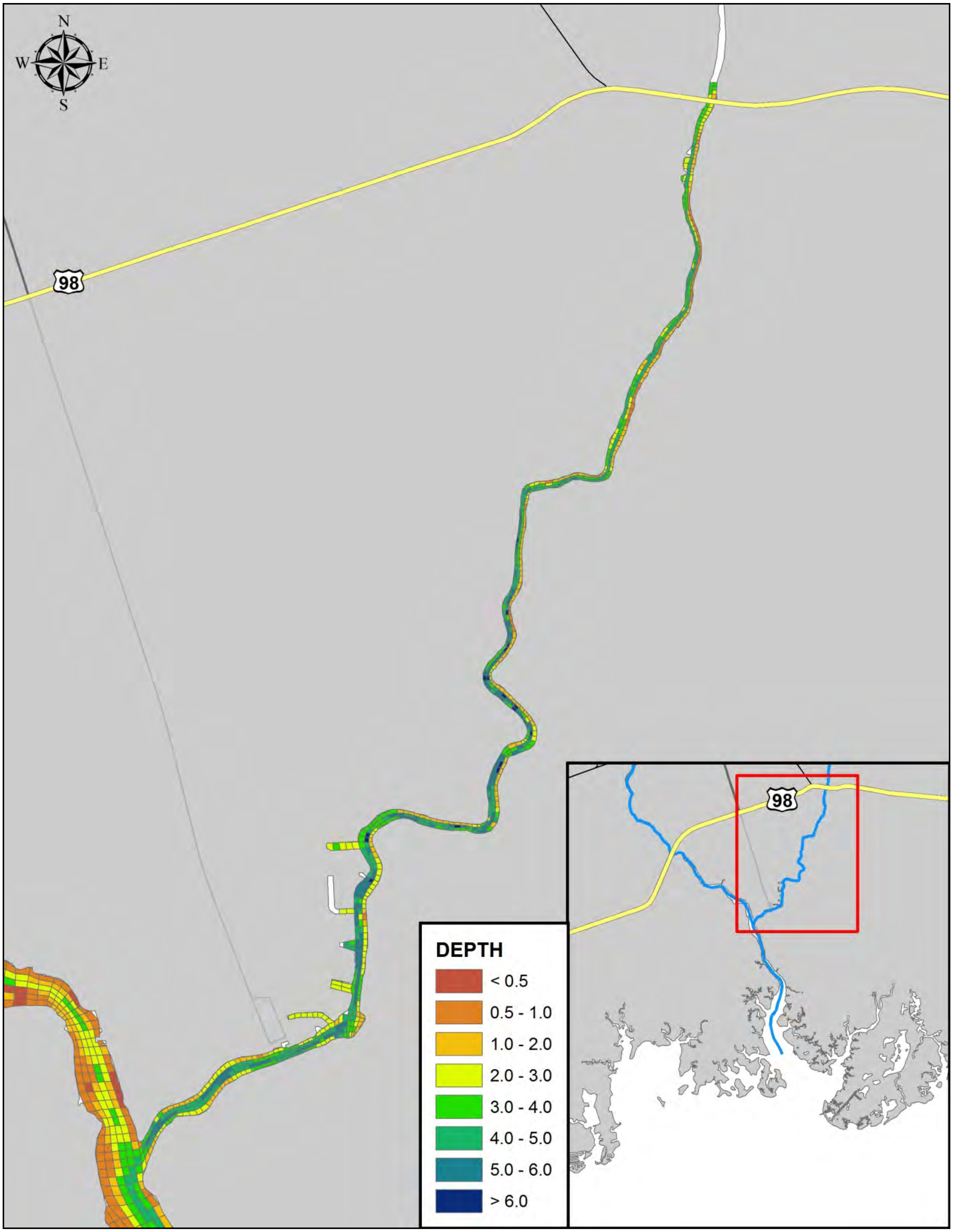

Figure 3. **Model grid and bathymetry for the St. Marks River upstream of the confluence within the model domain. Vertical reference is NAVD88, vertical (depth) units are meters.**

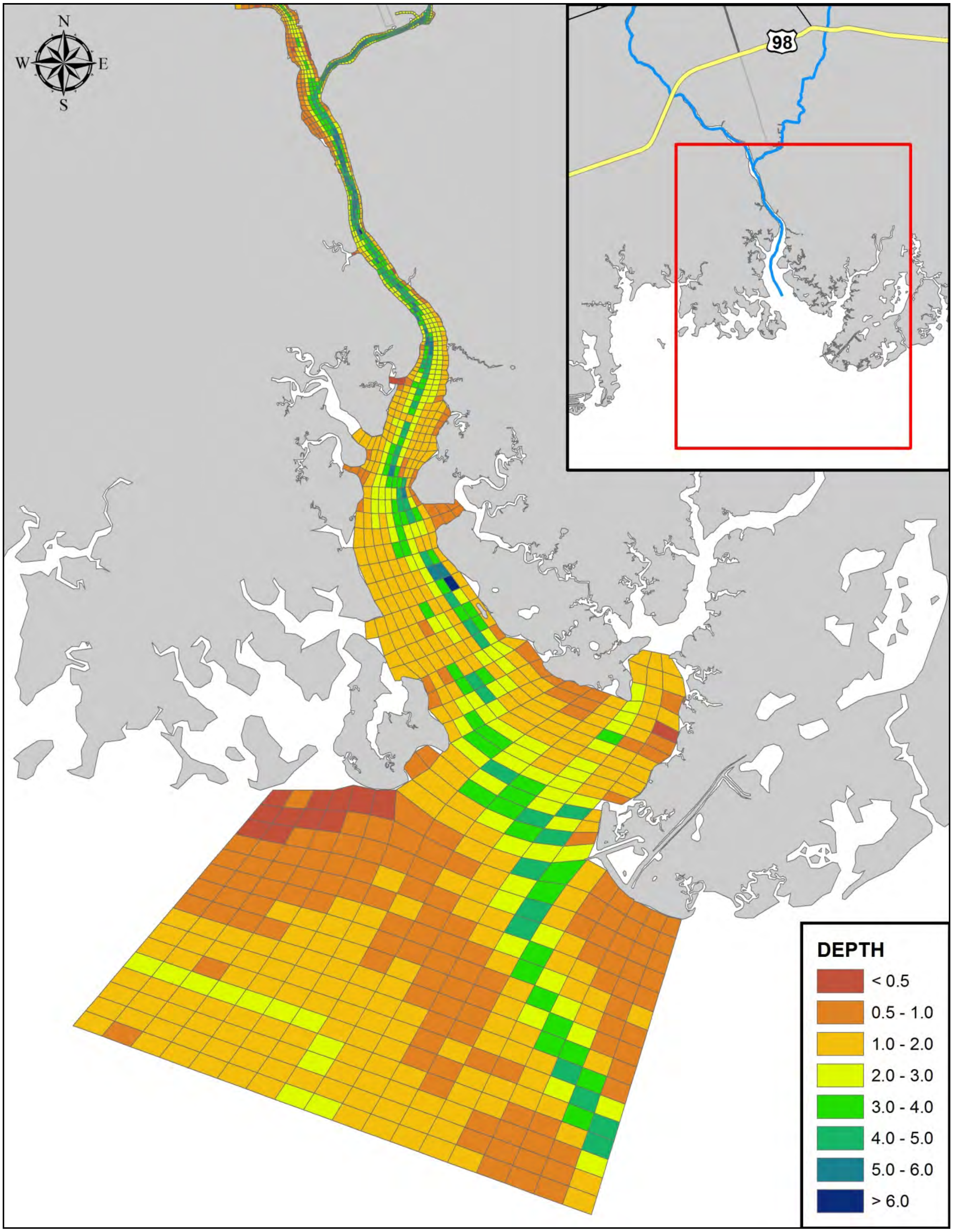

Figure 4. **Model grid and bathymetry for the St. Marks River from the confluence downstream to the offshore boundary of the model domain. Vertical reference is NAVD88, vertical (depth) units are meters.**

2.4 Model Calibration Period and Boundary Forcing Inputs

The time period selected for model calibration is May 11 - July 19, 2017. This period was selected based on the availability of reliable datasets for all input data types, including data from the continuous recorder at the mouth of the St. Marks River, HD-5 (Figure 1), which is used to determine offshore boundary conditions. Additional data needed for model input at the upstream sites in the rivers (HD-1 and HD-2, Figure 1) were also of high quality for this period. Water surface elevations, water temperature, and salinity were collected at 5-minute frequency over the calibration period at each of these sites.

The set of model files includes the following:

- ASER.INP: Contains hourly data for air temperature (°C), atmospheric pressure (mbar), relative humidity (fraction), rainfall (m/s), evapotranspiration (m/s), solar radiation (w/m^2), and cloud cover (fraction), obtained from the National Weather Service Tallahassee Regional Airport site. Daily evapotranspiration (ET) and hourly solar radiation data were obtained from the FAWN IFAS site at Monticello, FL. The locations of the various data collection sites providing data for the input files are provided in Figure 5. Time series of the data in the ASER.INP file are provided in Figures 6-12.

- WSER.INP: Contains 6-minute interval wind speed (m/s) and direction (true north) from the University of South Florida COMPS Shell Point site just west (~ 6 miles) of the mouth of the St. Marks River (Figure 5). These data were obtained from the National Data Buoy Center (NDBC), NOAA. See Figures 13-14.

- PSER.INP: Contains offshore boundary water surface elevations (m NAVD88) to recreate observed tidal forcing on the river system. The initial water surface elevations are those obtained from continuous recorder HD-5 at the mouth of the river (Figure 1), so that a relationship can be developed between the observed elevations at the mouth and those at the offshore grid boundary (approximately 3 km away), through a boundary matching process. The boundary matching process is an iterative process in which offshore forcing conditions are adjusted until the observed conditions at the river mouth are matched by the simulation. This allows for generation of offshore conditions, where no observations exist, to be developed for future model runs and periods. The data from HD-5 are at 5-minute frequency. See Figure 15.

- SSER.INP and TSER.INP: Contain salinity (ppt) (SSER) and water temperature (°C) (TSER) boundary conditions. Three time series of salinity and water temperature data are provided within each file. The first time series in each file is for the upstream boundary of the St. Marks River, taken from the observed data collected by the continuous recorder HD-1 (Figure 1). The second time series in each file is for the upstream boundary of the Wakulla River, taken from the observed data collected by the continuous recorder HD-2 (Figure 1).

The third time series in each file is for the offshore boundary, again taken from the observed data at HD-5 at the mouth of the river. All data are at 5-minute frequency. As for water surface elevation, revisions to the offshore salinity and water temperature boundary condition time series were made as part of the boundary matching effort included in the calibration effort. See Figures 16-21.

- SALT.INP and TEMP.INP: Initial conditions for salinity (SALT) and water temperature (TEMP) are based on continuous recorder data from HD-1, HD-2, HD-3, HD-4, and HD-5 (Figure 1). Model grid cells were assigned initial conditions based on observed data on May 11, 2017, with groups of grid cells assigned to each continuous recorder. See Figures 22-23.

- QSER.INP: Freshwater inflows at the upstream-most grid cells in each river, with flows taken from the St. Marks near Newport and Wakulla near Crawfordville USGS gages (02326900 and 02327022, respectively; Figures 1, 5). Data frequency is 15-minute from each gage. Flow units in the input file are m^3/s. To account for inflows from the ungaged watershed of the St. Marks River between the USGS gage near Newport and the upstream cell of the model domain, the gaged flow is increased by a factor of 1.28865. This factor was estimated as part of HEC-RAS work also being completed for this MFL and is based on estimated lateral ungaged inflows of 127 cfs when corresponding Newport gage flow was 440 cfs (Applied Technology and Management, Inc. 2017c). See Figures 24-25.

- Physiographic files associated with model grid, files CELL.INP, CELLLT.INP, DXDY.INP, MAPPGNS.INP, and LXLY.INP. These files are created during model grid development. The DXDY.INP file contains the horizontal dimensions, bottom elevation of each grid cell (m NAVD88), and the initial water depth in each cell, set with water surface elevation equal to 0 m NAVD88.

- Runtime display file SHOW.INP: provides for progress tracking during run.

- Main control file EFDC.INP and model executable EFDC_DS_100819C2.exe.

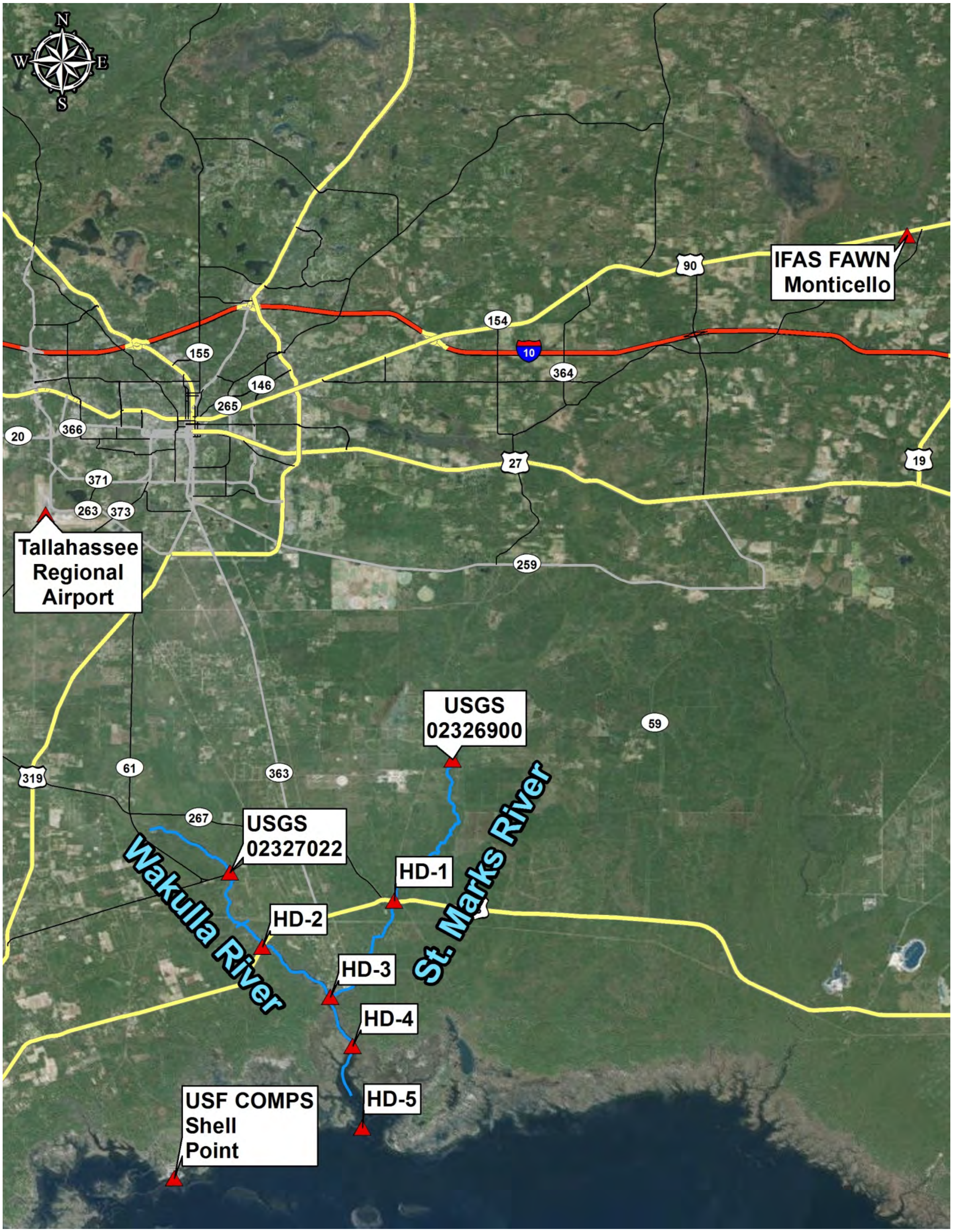

Figure 5. Locations of data collection sites for continuous recorders (HD-1 through HD-5), USGS flow gages, USF COMPS Shell Point winds, Tallahassee Regional Airport meteorology (including rainfall), and IFAS FAWN Monticello.

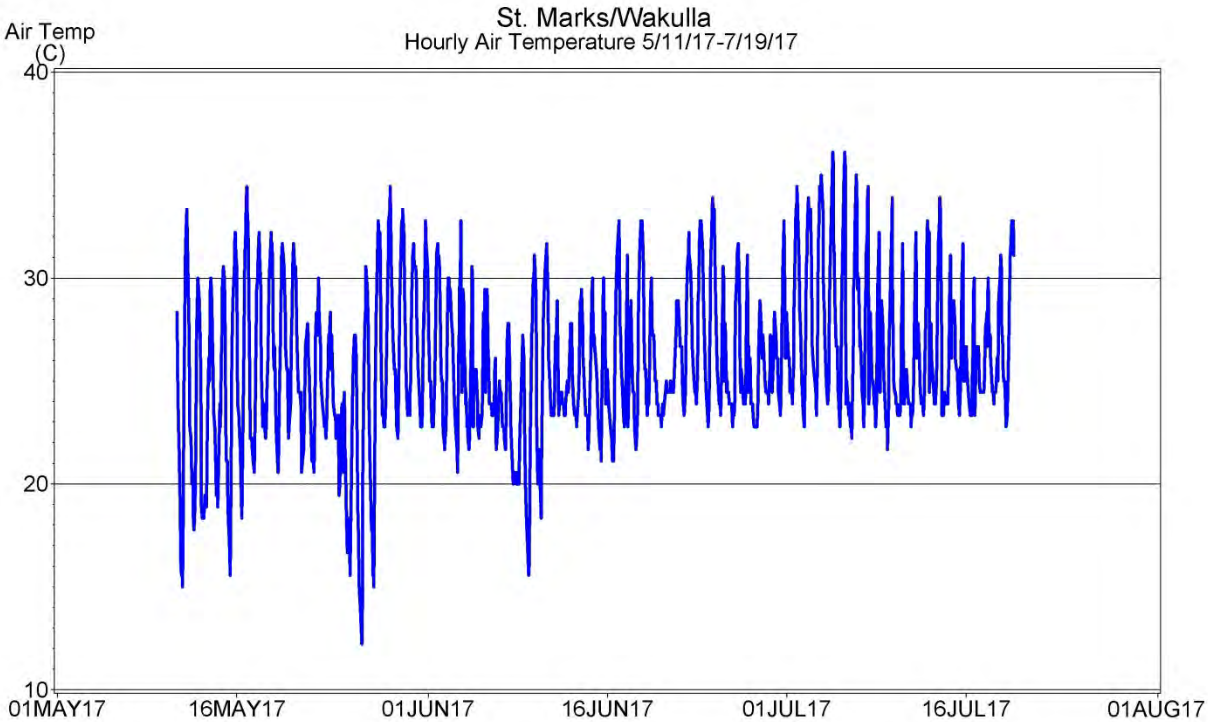

Figure 6. **Hourly air temperature from Tallahassee Regional Airport.**

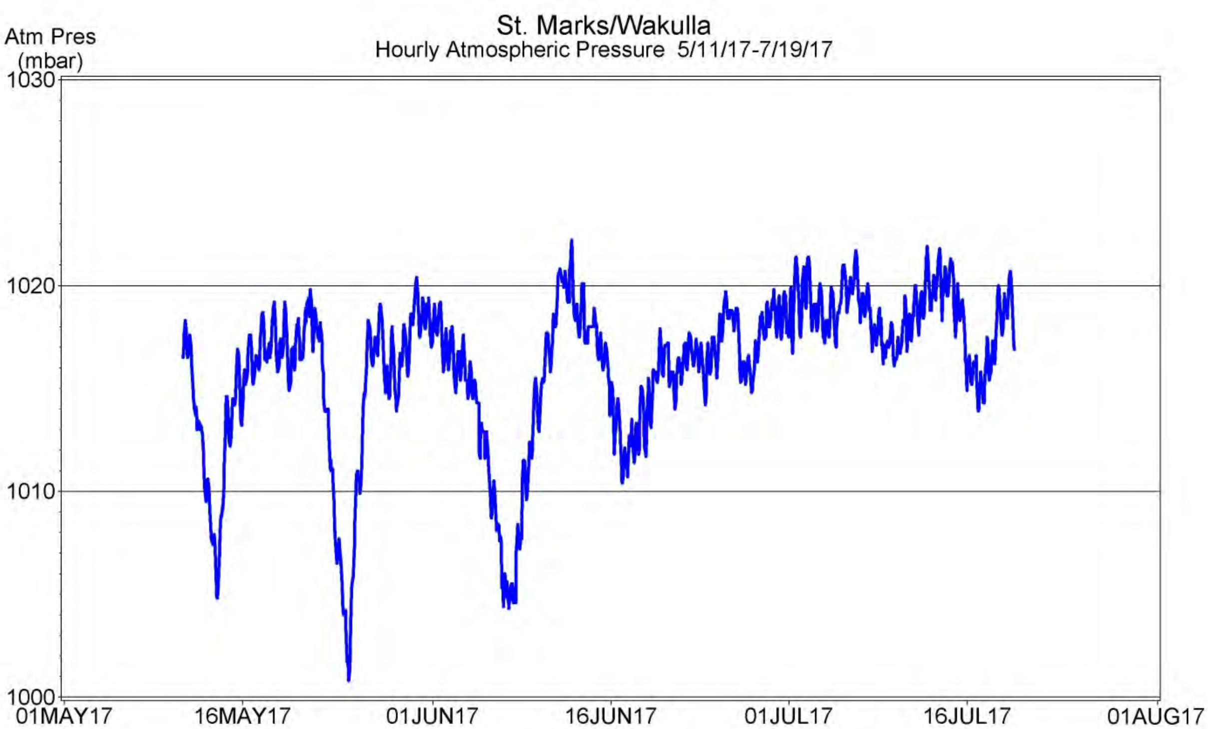

Figure 7. **Hourly atmospheric pressure from Tallahassee Regional Airport.**

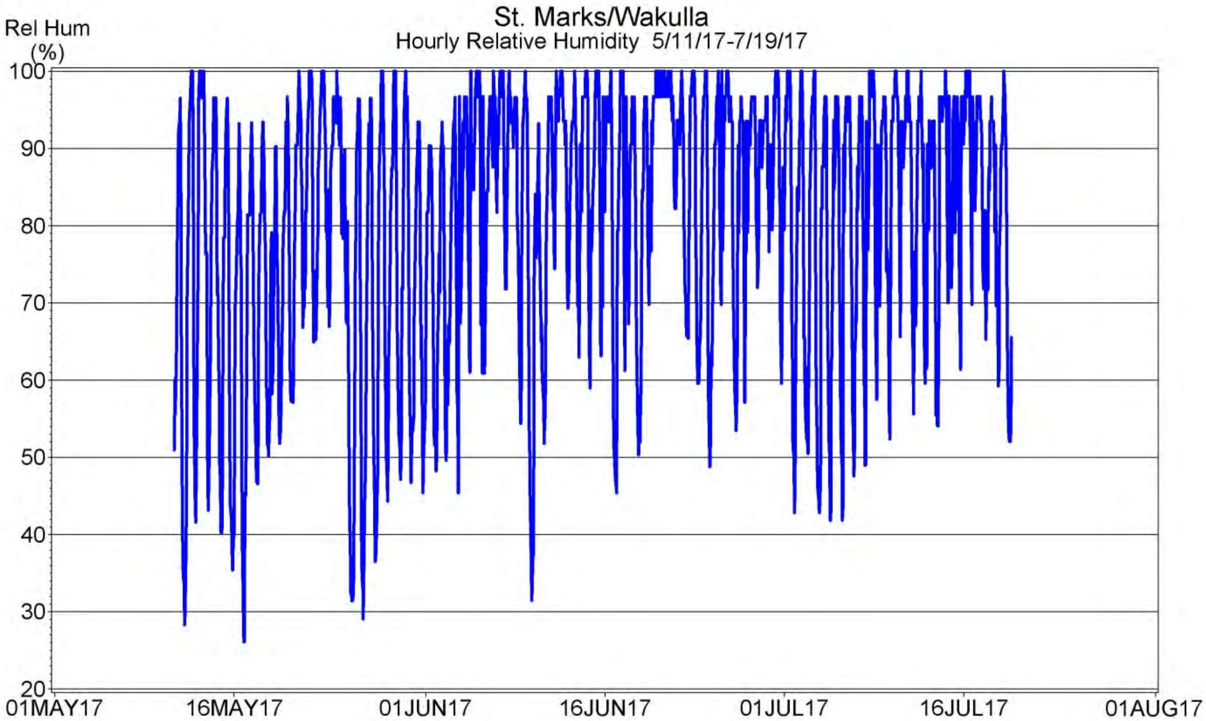

Figure 8. Hourly relative humidity from Tallahassee Regional Airport.

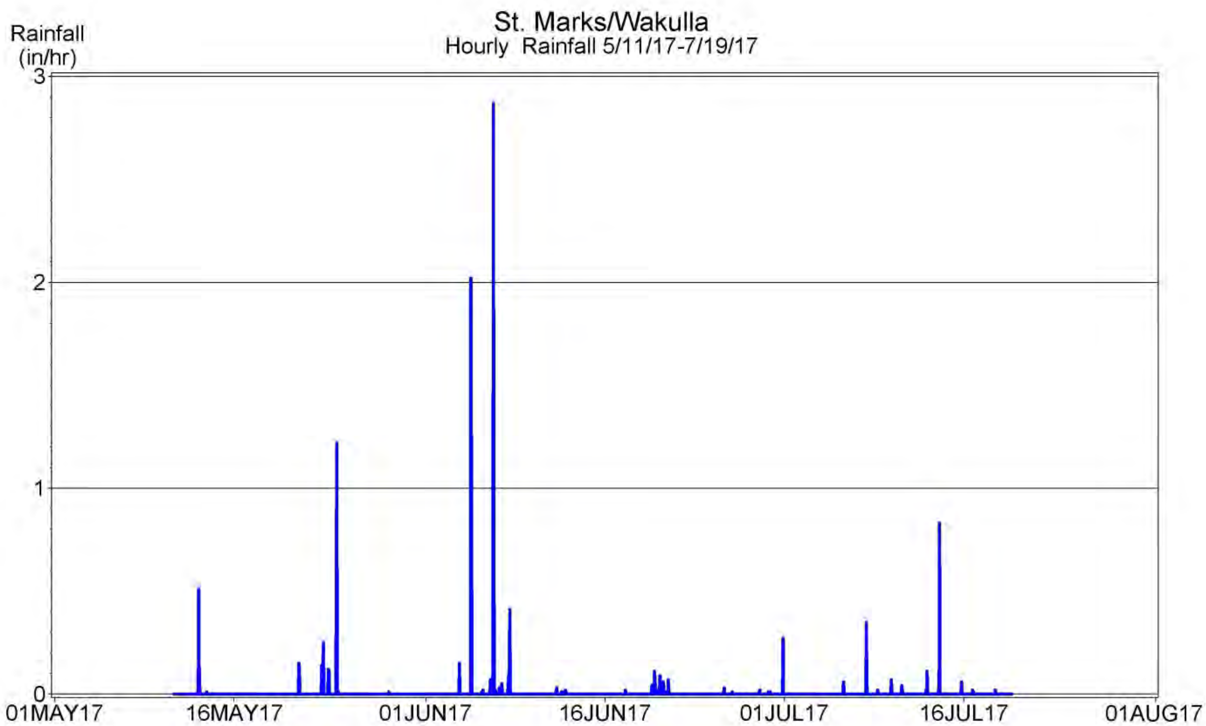

Figure 9. Hourly rainfall from Tallahassee Regional Airport.

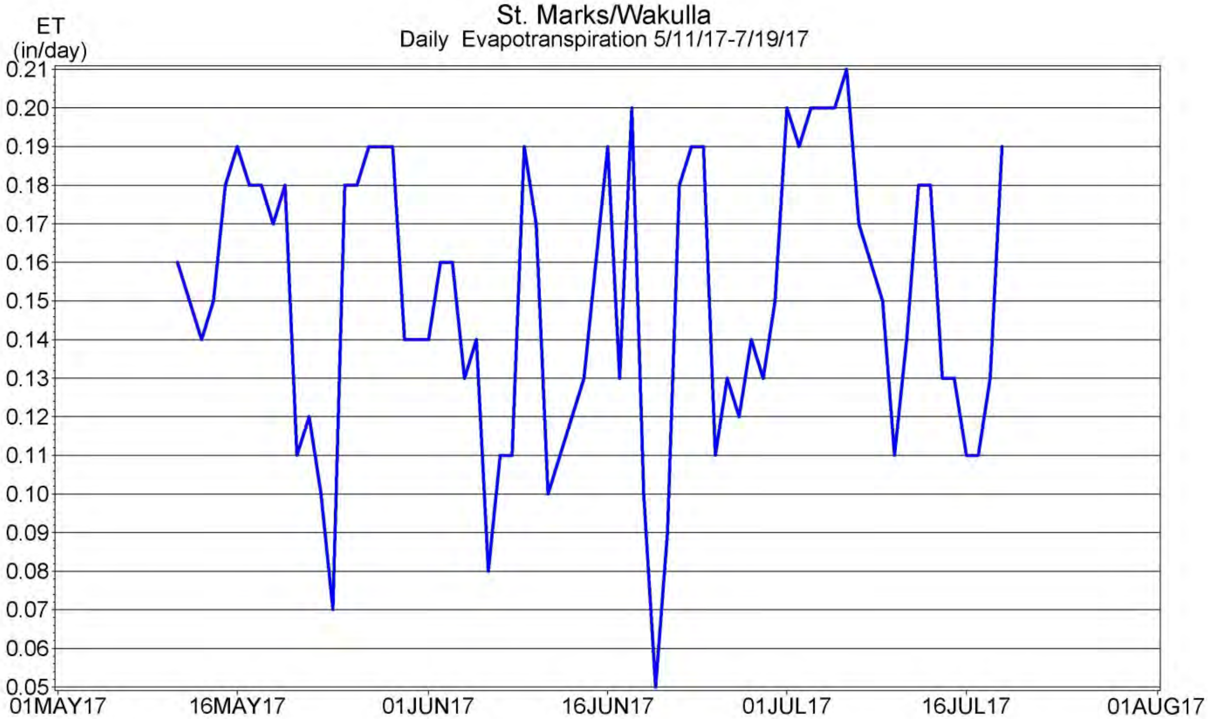

Figure 10. **Daily evapotranspiration from Monticello IFAS site.**

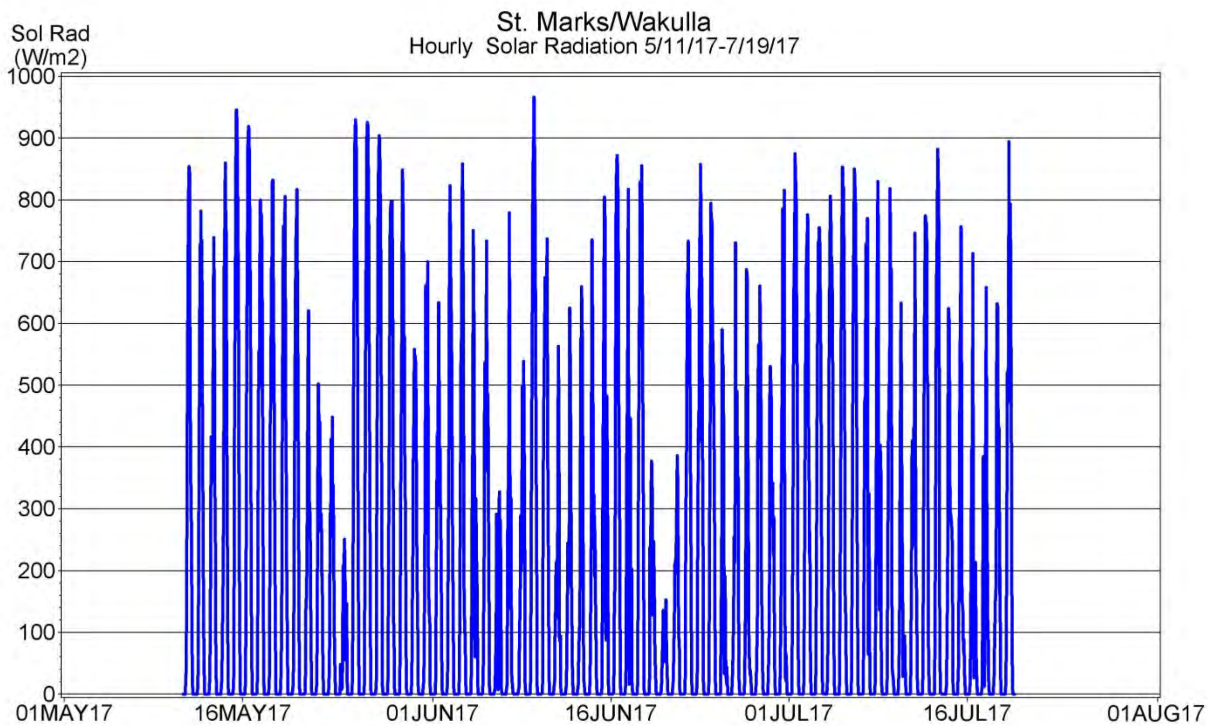

Figure 11. **Hourly solar radiation from Monticello IFAS site.**

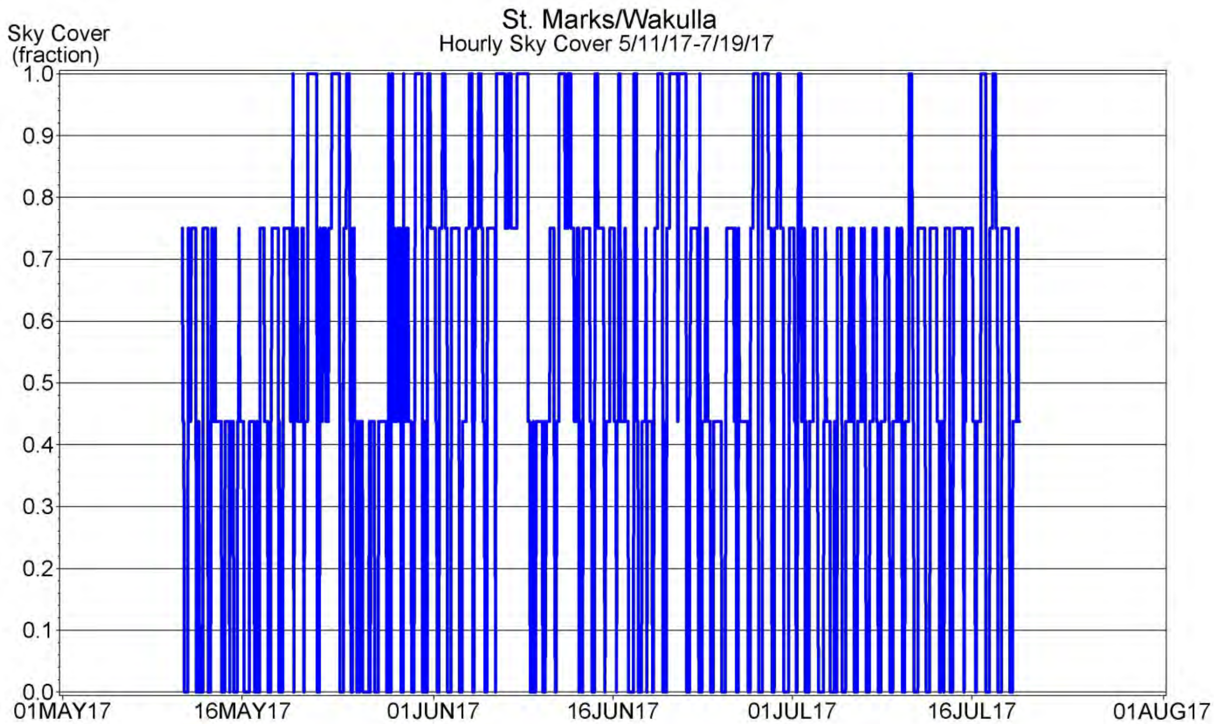

Figure 12. Hourly sky cover from Tallahassee Regional Airport.

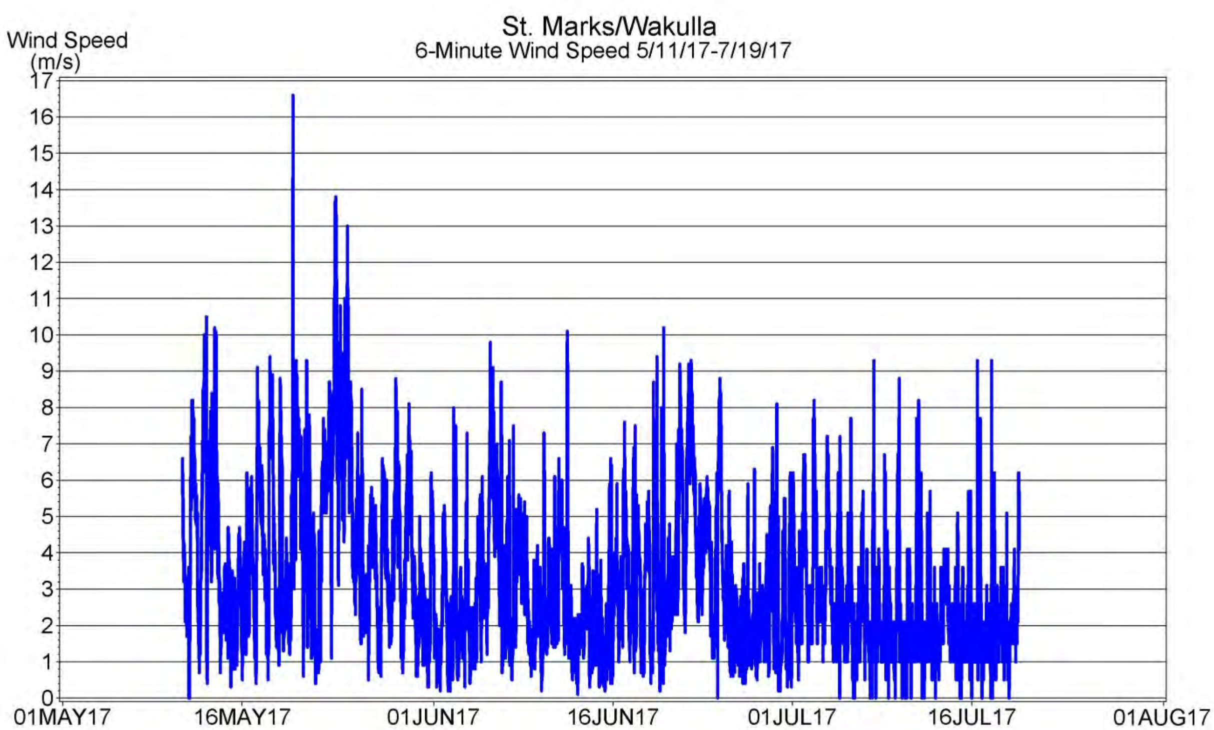

Figure 13. Six-minute wind speed from Shell Point site.

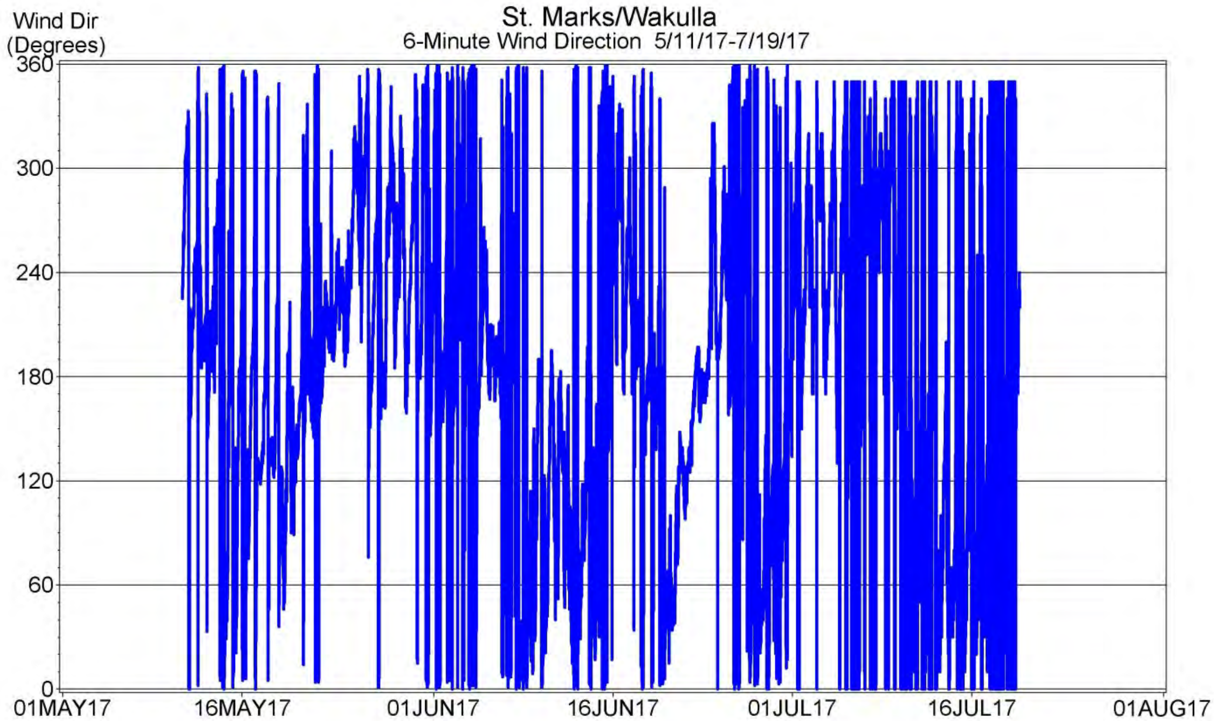

Figure 14. **Six-minute wind direction from Shell Point site.**

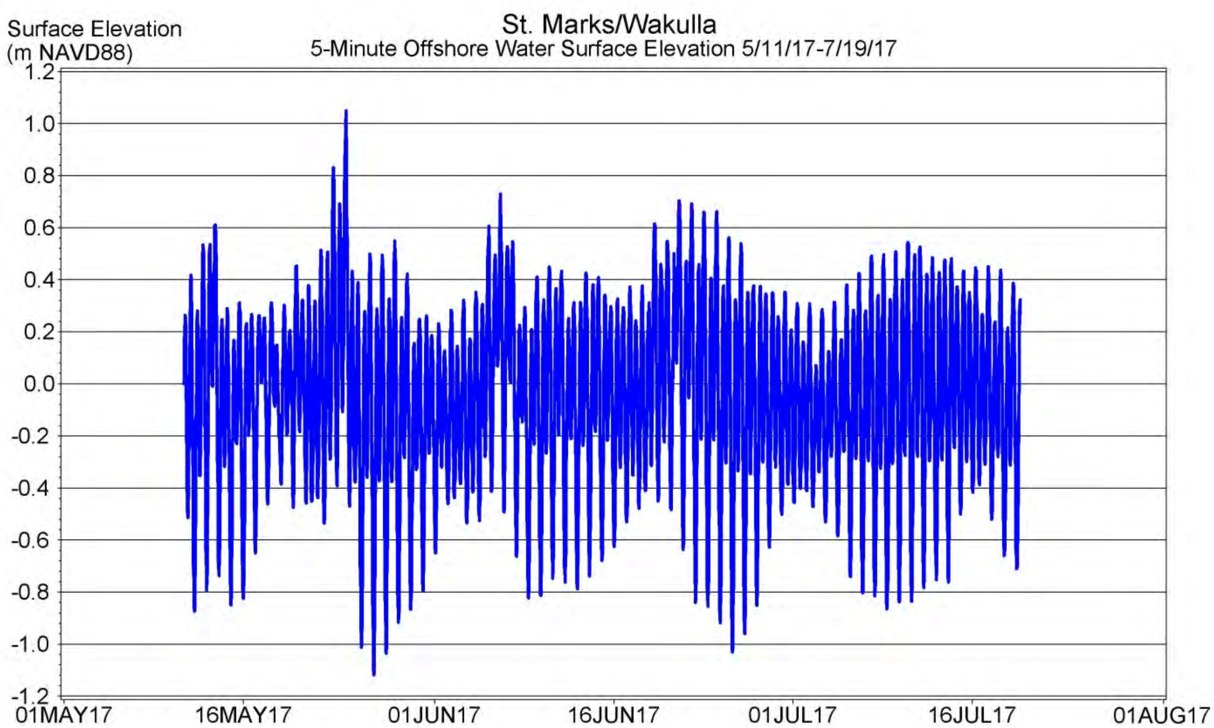

Figure 15. **Five-minute water surface elevation applied to offshore boundary, from HD-5.**

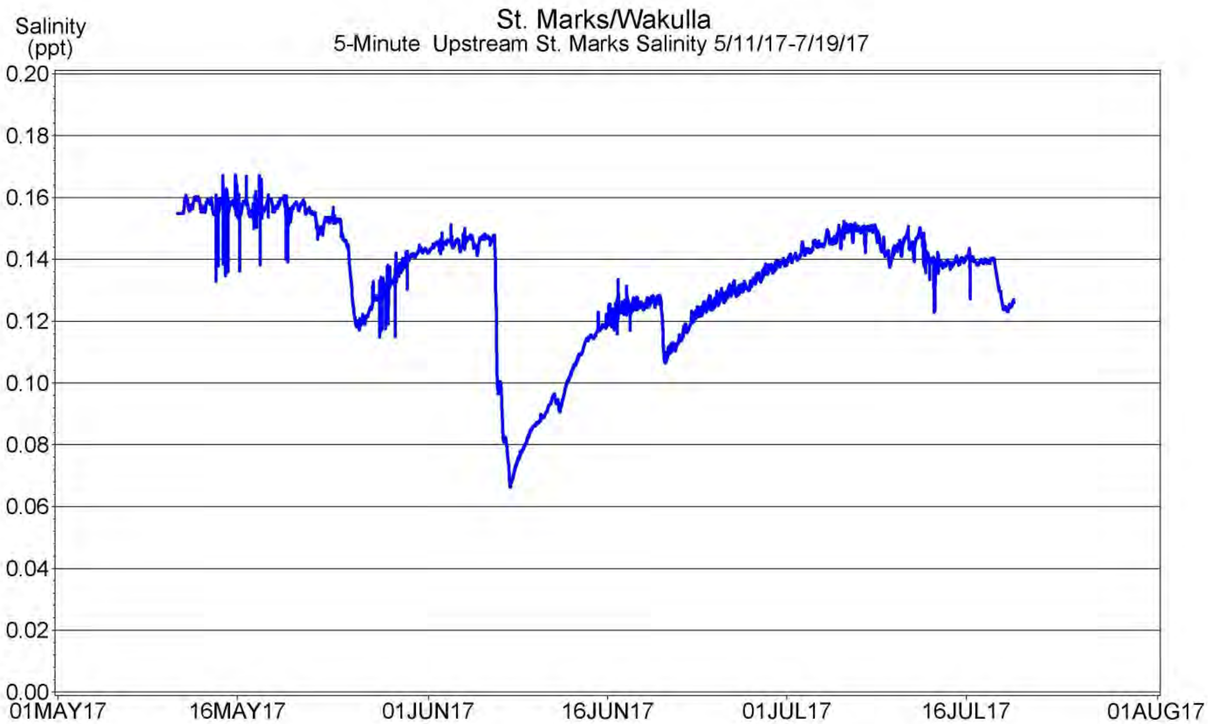

Figure 16. **Five-minute upstream salinity entering St. Marks River grids, from HD-1.**

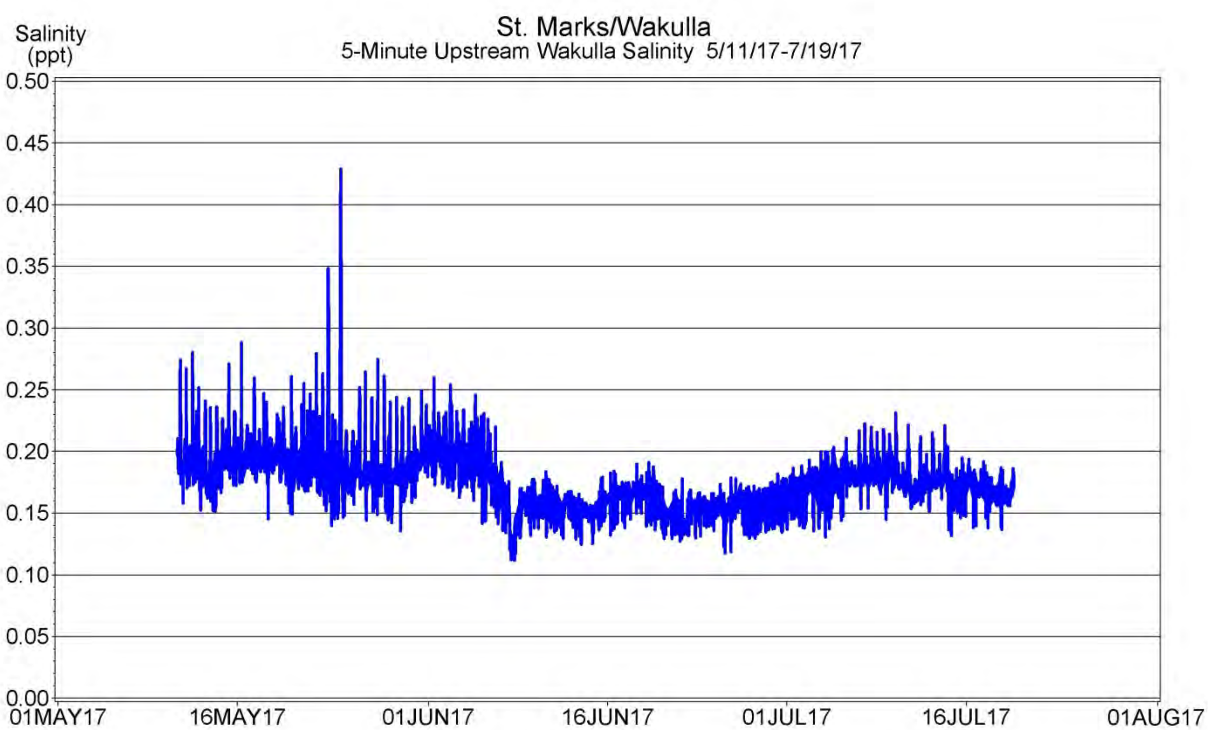

Figure 17. **Five-minute upstream salinity entering Wakulla River grids, from HD-2. The relatively high values (>0.4 ppt) occurred on 24May17, coincident with the relatively high water surface elevations at the river mouth shown in Figure 15 on the same day.**

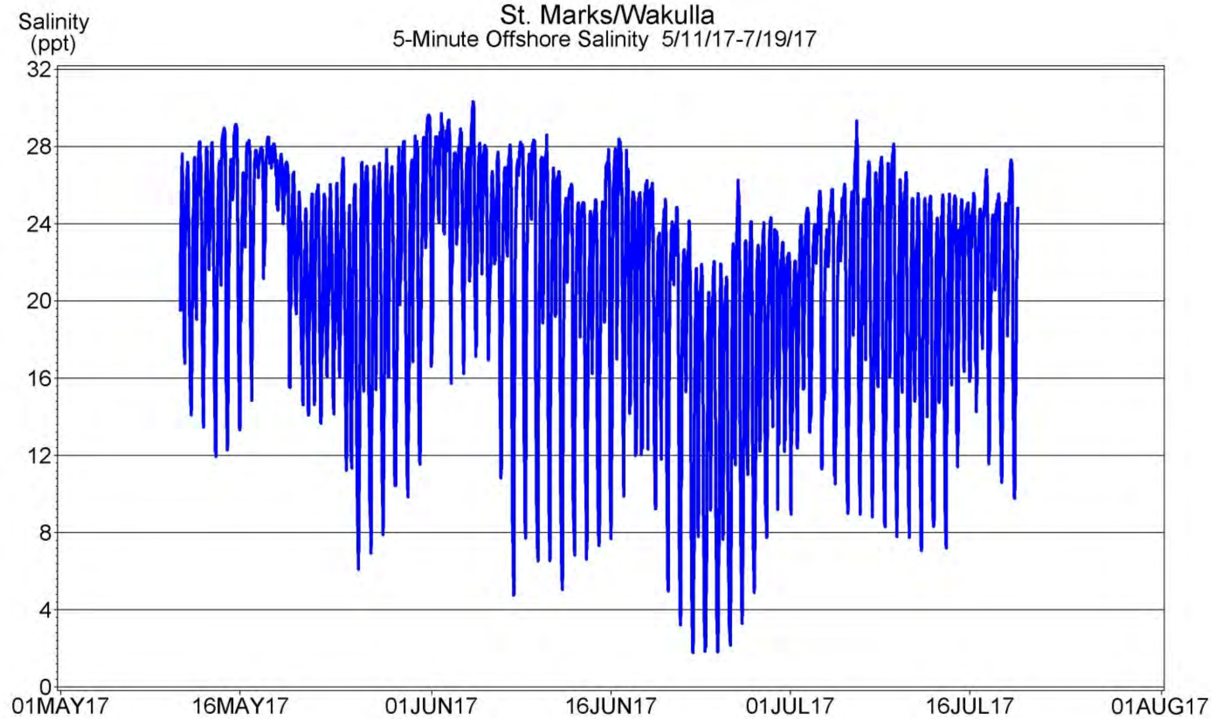

Figure 18. **Five-minute offshore salinity, from HD-5.**

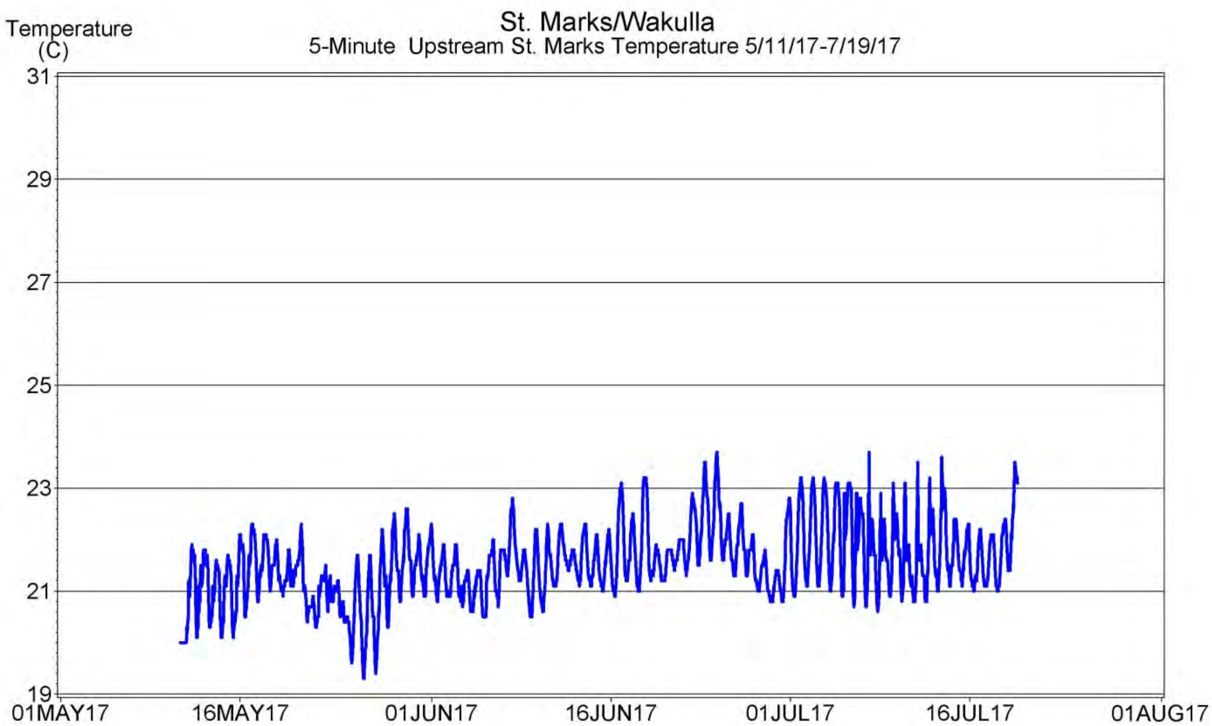

Figure 19. **Five-minute upstream water temperature entering St. Marks River grids, from HD-1.**

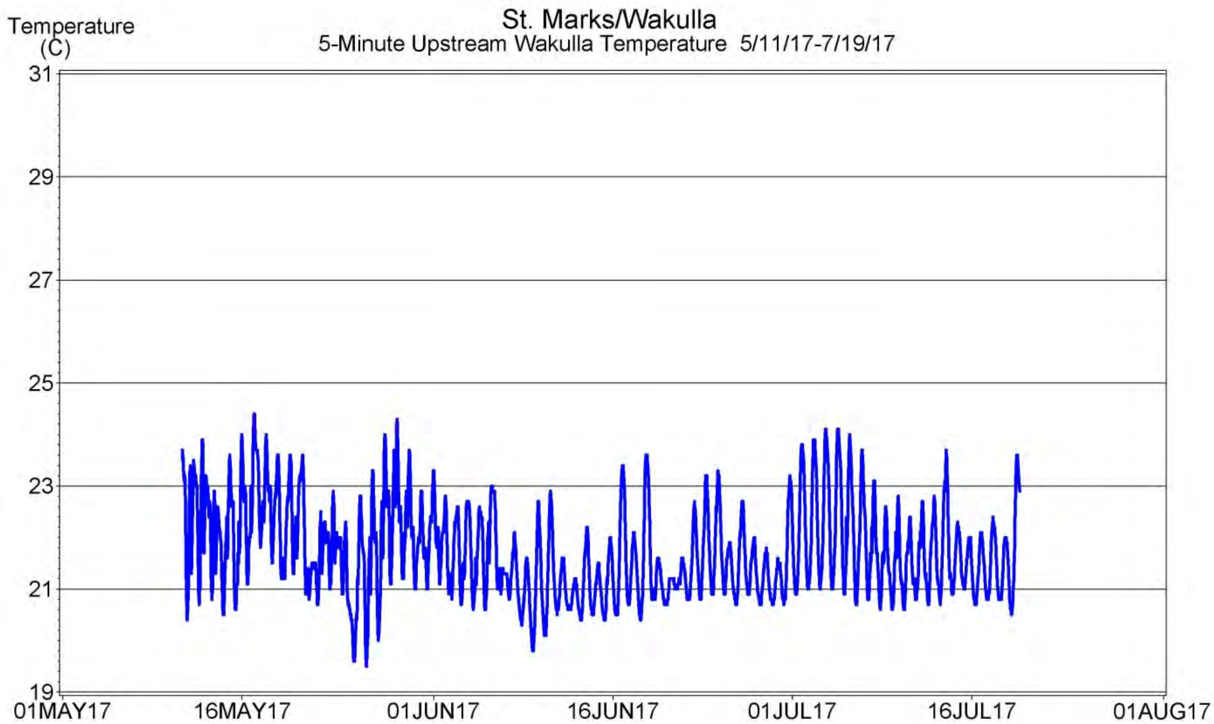

Figure 20. **Five-minute upstream water temperature entering Wakulla River grids, from HD-2.**

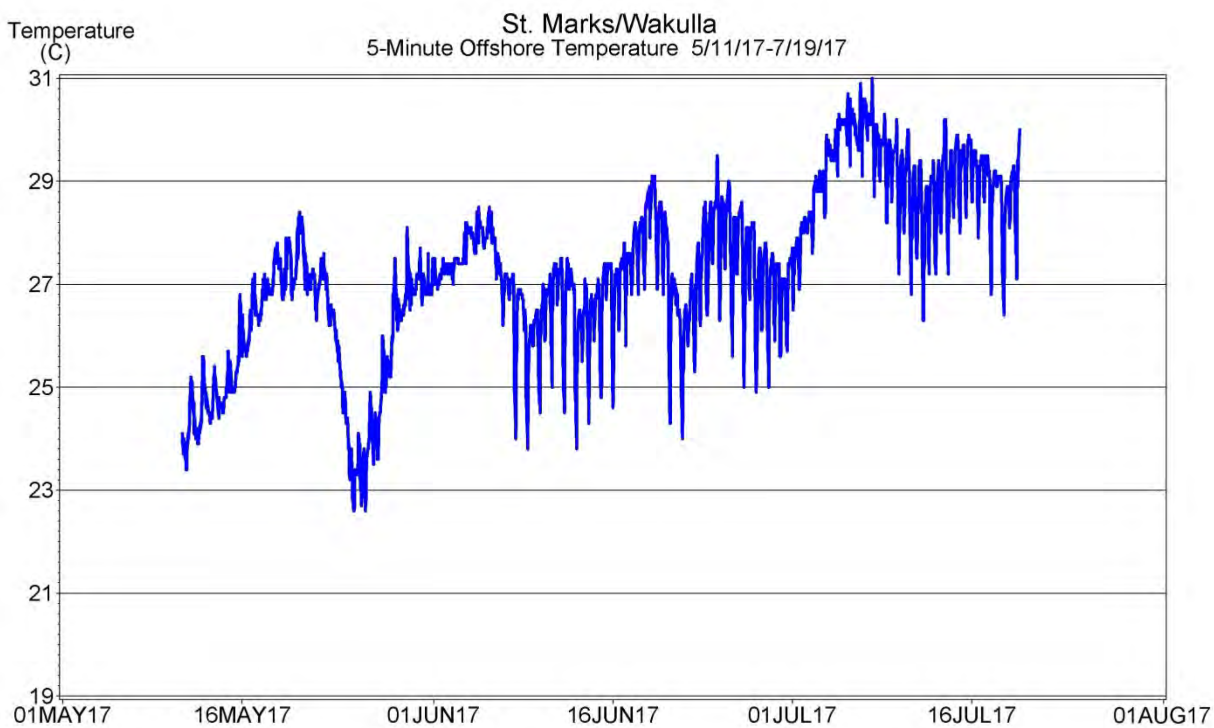

Figure 21. **Five-minute offshore water temperature, from HD-5.**

Initial Condition - Salinity (ppt)

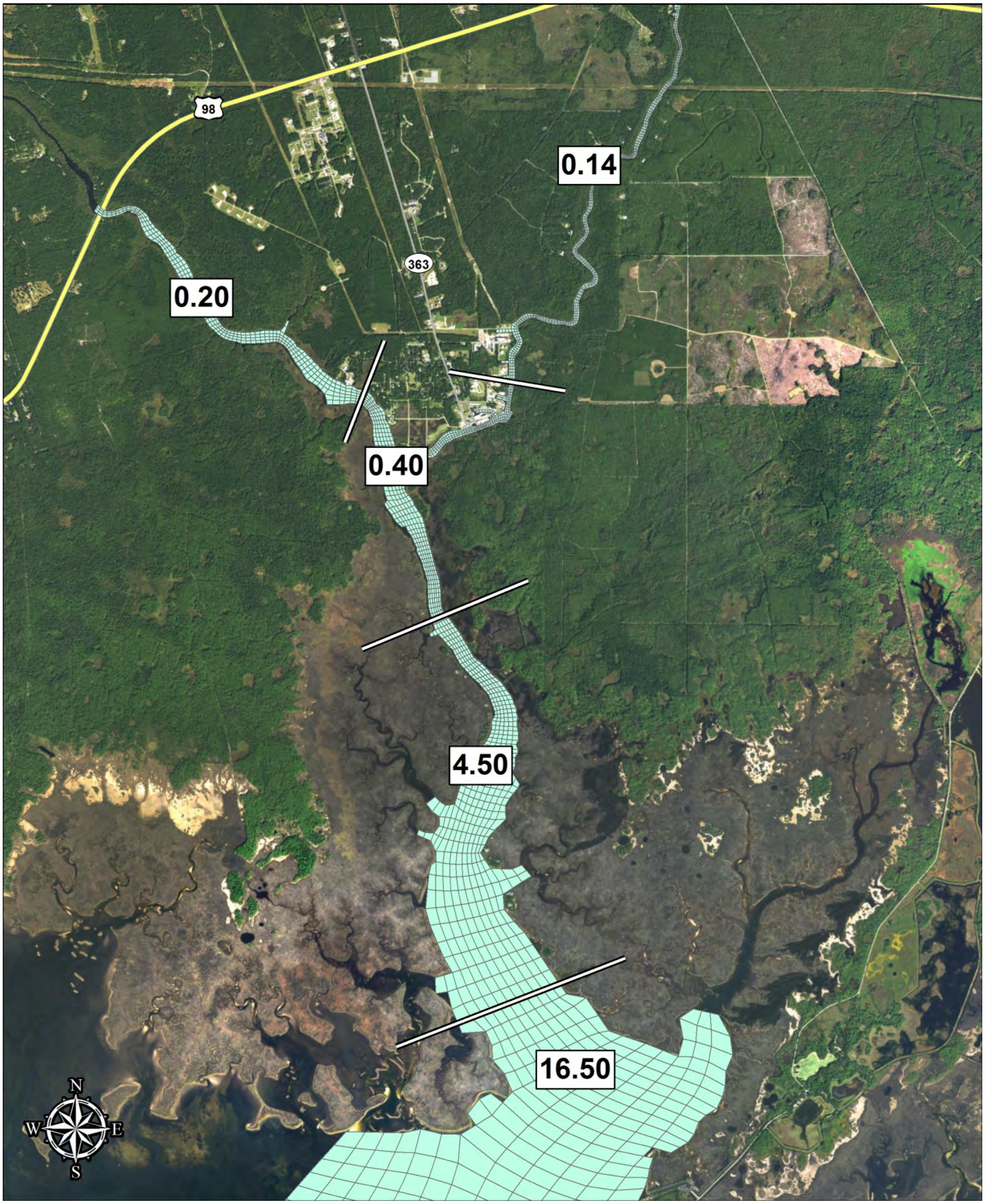

Figure 22. **Initial condition salinity developed from continuous recorders.**

Initial Condition - Temperature (C)

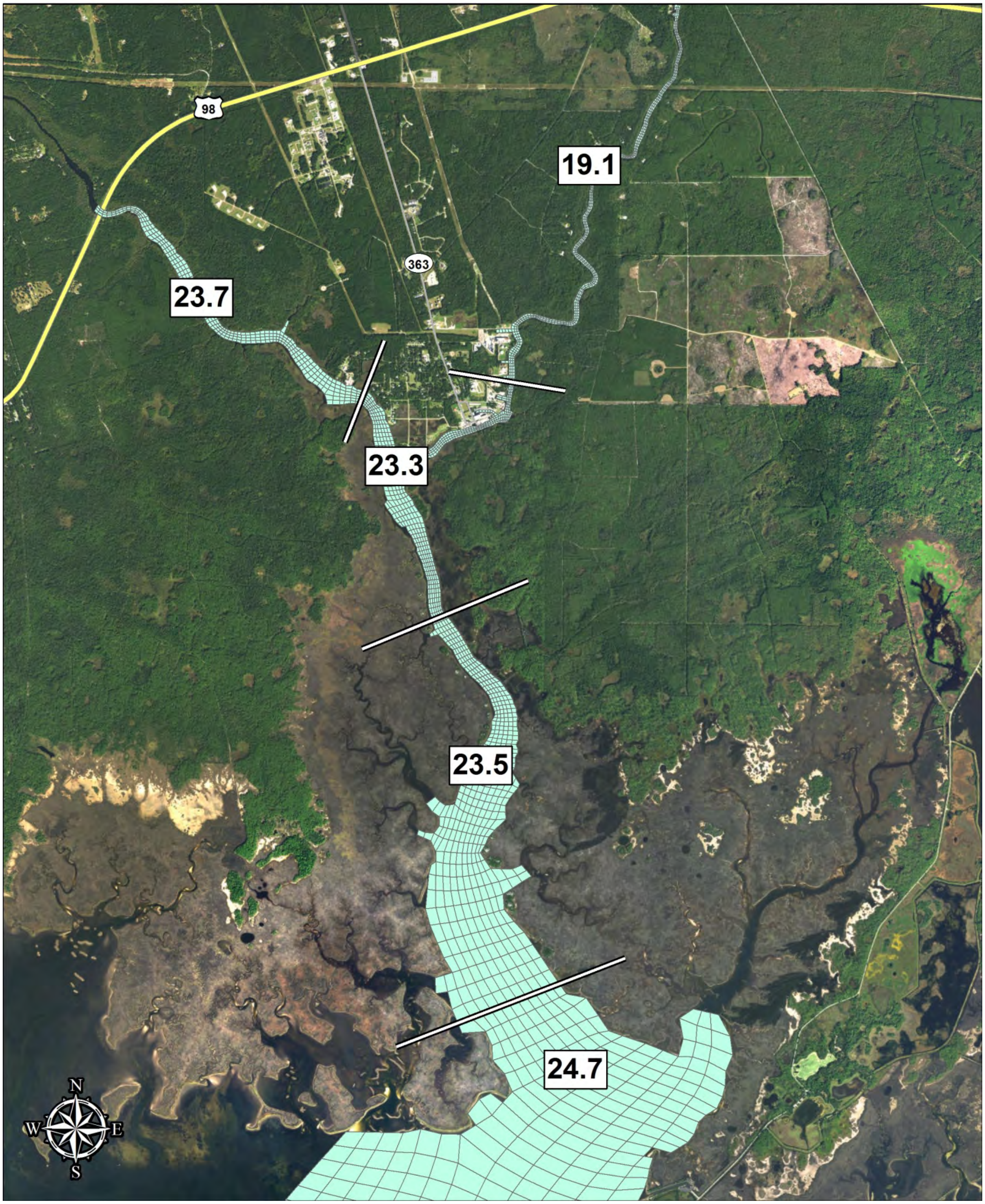

Figure 23. Initial condition water temperature developed from continuous recorders.

Figure 24. **Inflows to model domain from upstream St. Marks River.**

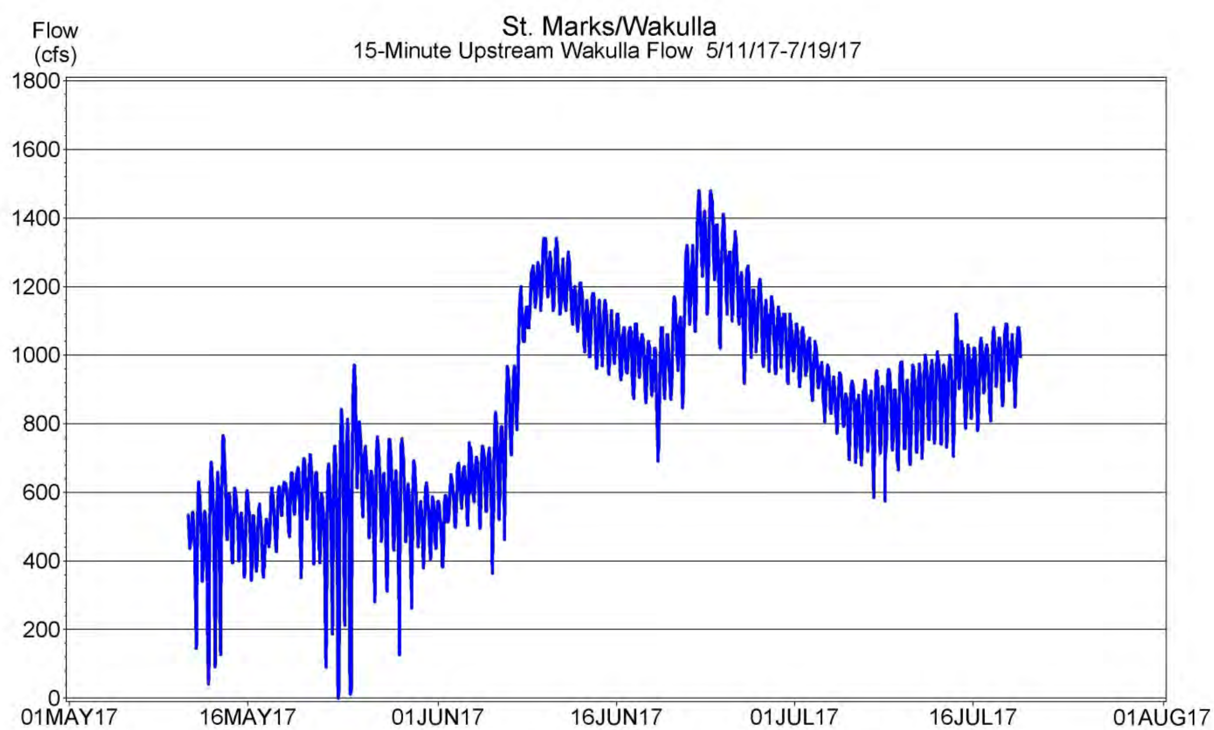

Figure 25. **Inflows to model domain from upstream Wakulla River.**

3 EFDC Hydrodynamic Model Calibration

This section provides a description of the calibration of the hydrodynamic model, including definition of the model skill assessment metrics, as well as presentation of results for water surface elevation, salinity, and temperature. Additionally, simulated total mass fluxes over a tidal cycle in the river downstream of the confluence for a day with conditions similar to those when actual flux measurements were taken on 11Apr17 are provided.

Comparisons of simulated and observed data were performed to optimize the calibration. Calibration consists of evaluation of model results from a given set of inputs (bathymetry, inflows, tidal boundaries, atmospheric inputs) against observed conditions, then interative revision of inputs, typically bathymetry and associated bottom roughness coefficient, to optimize the model's ability to simulate observed water surface elevations and salinity and temperature distributions. This process is performed using best professional judgment based on experience gained in numerous other model calibration efforts. The comparisons to observed data included the following data types:

- Water surface elevation data collected at all five continuous recorder sites (HD-1, HD-2, HD-3, HD-4, and HD-5) (Figure 1). For this effort, the water surface elevations at HD-5 were revised based on discussion with Paul Thurman (District), with water surface elevations increased by 0.209 m to account for measurement error in the initial elevation survey for the pressure sensor.
- Surface and bottom salinity and temperature data collected at HD-5, HD-4, and HD-3. The salinity and temperature data from the continuous recorders at HD-1 and HD-2 served as input upstream boundary conditions for the upstream ends of the model. To ensure proper input of these upstream boundary conditions, the simulated salinity and temperature within the upstream-most cells were compared to the upstream boundary conditions, and were almost identical (some small changes within these upstream-most cells from the boundary conditions are expected, but are very minimal). Sites HD-1 and HD-2 were not used for statistical comparisons between simulated and observed salinity and temperature since the simulated values were constrained so closely by the observed conditions used as input.
- Additional comparison is made to the salinity longitudinal profile data collected between May 2016 and April 2017 in the St. Marks River both upstream and downstream of the confluence (Figure 26). The focus of this comparison was to ensure appropriate behavior of the model in predicting similar responses in salinity distribution along the longitudinal axis of the St. Marks River to similar inflows. An effort to match up observed data and simulated data from the different time periods was accomplished as described below.

Time series comparisons are provided in Attachment 1 for those periods during which observed data were available for the 11 May 2017 to 19 July 2017 calibration period. Time series are provided for water surface elevation at HD-1 through HD-5, and for salinity and temperature at HD-3 through HD-5. To aid in visualization, the 70-day calibration period was broken up into 10-day intervals for each time series graphic in Attachment 1. For those 10-day periods during which observed data did not exist, no plots are provided (water surface elevation at HD-3 for days 60-70; bottom salinity and temperature at HD-3 for days 60-70; surface salinity and temperature at HD-5 for days 0-20).

The calibration process included revisions to initial bathymetry as developed from bathymetry data collected specifically for this project. The resulting grid bathymetry is provided in Figures 2-4 above, and is included in a separate input file (DXDY.INP). The offshore boundary is approximately 3 km into the Gulf from HD-5.

Offshore boundary conditions were applied to the one open boundary of the offshore grid, along the southeastern side, so that the elevation, salinity, and temperature signals supplied at this boundary could travel upstream via the deeper channel connecting the offshore area to the mouth of the river (see Figure 4). For the model calibration, the offshore water level boundary conditions were developed from measured water levels at the mouth (HD-5) using boundary matching techniques. This included evaluation of time delay and slight revisions to main channel bathymetry from the offshore boundary to the river mouth. In the final calibration, the tidal signal at the boundary was shifted 5 minutes back in time so that the simulated signal at HD-5 matched that observed, and there was no revision to the offshore bathymetry as initially developed. The offshore salinity boundary conditions were derived from the daily maxima of the continuous salinity measured at the mouth (HD-5).

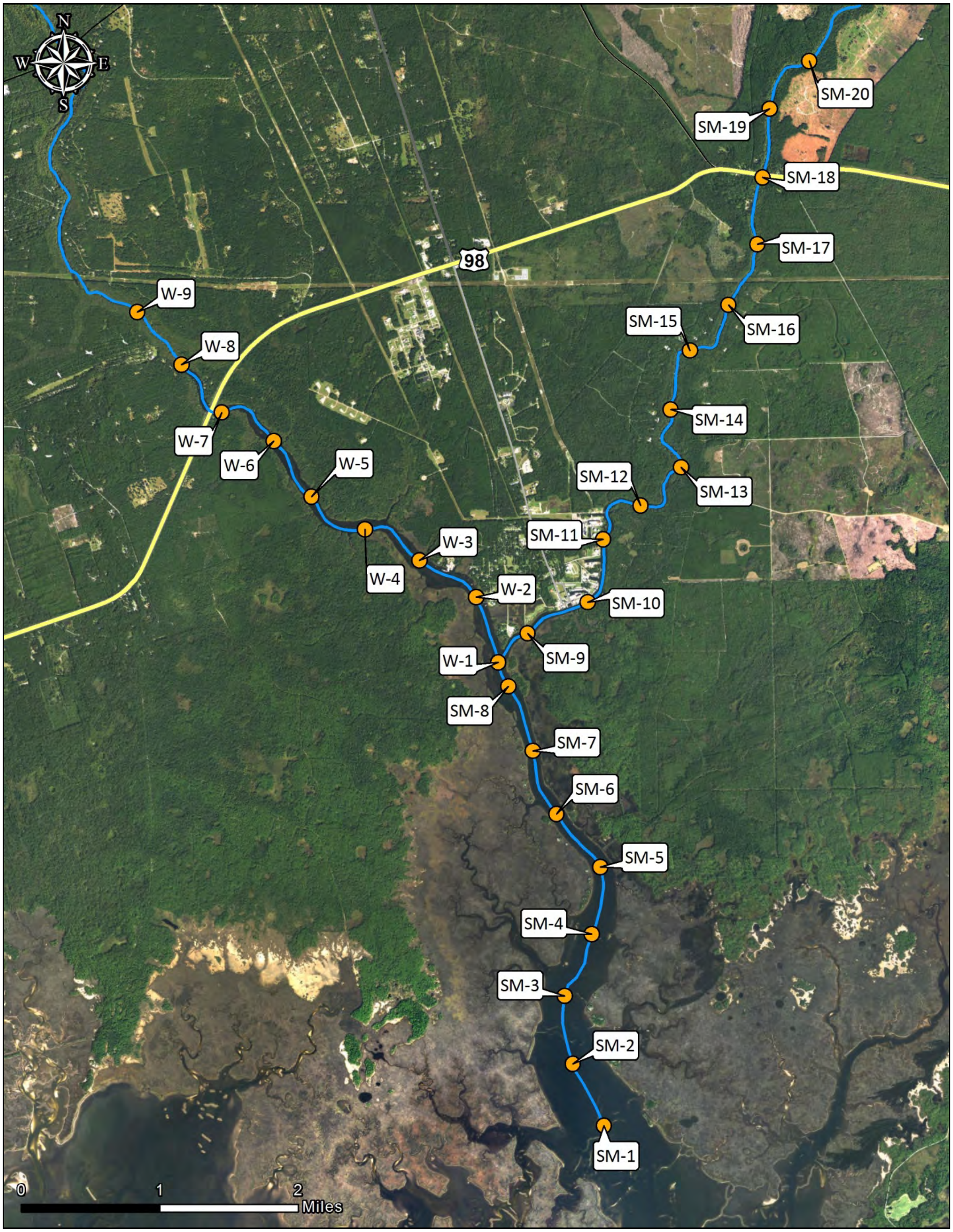

Figure 26. Locations of vertical profile sampling sites in St. Marks River and Wakulla River.

In addition to graphical comparisons of the simulated versus measured time series results, statistical comparisons were performed, where appropriate. The statistics include the mean error (ME), mean absolute error (MAE), root mean square error (RMSE), and the coefficient of determination (R^2). The following presents how each of these error statistics are calculated.

MEAN ERROR

$$\mathrm{ME} = \frac{1}{n}\sum_{i=1}^{n}(P_\mathrm{i} - O_\mathrm{i})$$

MEAN ABSOLUTE ERROR

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}|P_\mathrm{i} - O_\mathrm{i}|$$

ROOT MEAN SQUARE ERROR

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}}$$

COEFFICIENT OF DETERMINATION

$$\boldsymbol{R^2} = \frac{[\boldsymbol{n}\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}}\boldsymbol{O_i}\,\boldsymbol{P_i} - (\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}}\boldsymbol{O_i})(\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}}\boldsymbol{P_i})]^2}{\left[\boldsymbol{n}\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}}(\boldsymbol{O_i})^2 - (\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}}\boldsymbol{O_i})^2\right]\left[\boldsymbol{n}\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}}(\boldsymbol{P_i})^2 - (\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}}\boldsymbol{P_i})^2\right]}$$

where: O_i = observation
P_i = model (predicted) output
n = number of observations

The data output from the model were extracted to match times of available measured data for the analyses. The statistics were then calculated from the matched data sets for each site over the entire 70-day calibration period.

The RMSE represents the deviation of each of the individual measured-versus-simulated matched data pairs and is the most direct measurement of model-to-simulation error or difference between the results. This measure does not have a sign (i.e., negative or positive), so it does not identify if this is an under-prediction or over-prediction, simply what the overall differences are. The ME represents whether or not there is a bias in the results. For example, if the ME is less than zero, it means that overall, the model is under-predicting in an absolute sense. For both the RMSE and the ME, the results are presented as values in the units of measure (centimeters [cm] for water level, parts per thousand [ppt] for salinity, and degree C for temperature). The coefficient of determination (R^2) is a measure of how the model and data line up or correlate. If the model and data lined up perfectly, the R^2 value would be 1.

The skill assessment results for water surface elevation are provided in Table 2, and those for salinity and temperature are provided in Table 3. These skill assessment values for water surface elevation are very similar to those resulting from other west Florida shelf estuarine river systems previously simulated for MFL development (ATM, 2015; Janicki Environmental, 2015b).

Table 2. Skill assessment results for water surface elevation for 11May17 - 19Jul17.

Location	ME (cm)	MAE (cm)	RMSE (cm)	R^2
HD-5	0.9	2.7	4.1	0.99
HD-4	2.4	4.0	5.1	0.99
HD-3	0.4	1.3	3.4	0.97
HD-2	-4.9	8.0	10.5	0.90
HD-1	-2.0	7.8	10.0	0.92

For salinity and temperature, the skill assessment values provide additional input as to the degree of model responsiveness to observed forcing functions (flows, tides, etc.). The upstream-most stations HD-1 and HD-2 were beyond the reach of observed salinity intrusion during the calibration period as well as on all days when the profile data were collected, so that no error statistics for salinity and temperature are presented for these sites. Due to the nature of the salinity data and model simulations, with intermittent time frames where the salinity intrusion reaches HD-3, the error statistics must be understood to be a secondary measure of the model's capabilities. The nature of a salinity intrusion from the Gulf is such that often a very sharp salinity front moves up into the system, with the greatest level of intrusion occurring during neap tide conditions, when the energy is low and the level or sharpness of the stratification is highest. Due to the sharpness of the salinity front, a small error in the horizontal distance of the intrusion can result in a significant error in the salinity as the front moves up the system. For example, if the level of the salinity front intrusion in the model is 100 m short of the location of the station where salinity measurements are taken, the data could show that salinities might reach on the order of 10 to 15 ppt on the bottom, but the model simulations could show zero salinity, even though the modeled intrusion level was only a short distance below the gage location. Additionally, models, by their nature, tend to smear sharp gradients based on the level of model vertical or horizontal resolution. For the St. Marks/Wakulla model, the balance between having feasible run times for model scenarios and vertical resolution (needed to represent the sharp nature of the stratification in the system) lead to running the model with six vertical layers. While providing relatively good resolution in comparison with the depths, this level of vertical resolution still created some vertical smearing of the salinity profile. This result is very similar to those from the modeling efforts associated with the development of recent MFLs for the nearby Aucilla River and Econfina River (ATM, 2015, and Janicki Environmental, 2015b, respectively). As a result of these issues, the graphical comparisons show that the model is doing well simulating the upstream extent of the salinity intrusion and the overall magnitude response at the surface and bottom. A key aspect is that during the entire 70-day calibration period, during both low flow (early) and higher flows (late), the model shows that the level and timing of intrusions measured at HD-3 were acceptable given the variability in the system. These results support the model's capability to adequately simulate the variations in salinity intrusion under varying freshwater inflow and tidal forcing conditions.

Table 3a. **Error statistics for measured versus simulated salinity.**				
Site	**ME (ppt)**	**MAE (ppt)**	**RMSE (ppt)**	**R^2**
HD-5 Surface	0.4	2.5	3.5	0.50
HD-4 Surface	0.2	1.7	2.6	0.30
HD-5 Bottom	1.9	3.0	4.2	0.63
HD-4 Bottom	3.6	4.8	5.8	0.27
HD-3 Bottom	-0.1	0.1	0.7	0.12
Table 3b. **Error statistics for measured versus simulated temperature.**				
HD-5 Surface	-0.5	0.7	1.0	0.63
HD-4 Surface	-0.5	0.9	1.1	0.51
HD-5 Bottom	0.4	0.8	0.9	0.78
HD-4 Bottom	0.3	1.2	1.5	0.35
HD-3 Bottom	-0.2	0.2	0.5	0.49

An additional test of the model's responsiveness to observed forcing conditions was performed by utilizing a cross-river water flux study completed on April 11, 2017 (ATM, 2017a), downstream of the confluence. The inflows as measured at the USGS gage near Newport were multiplied by a factor, 1.28865, to yield the inflows at the upstream end of the model domain in the St. Marks River. As mentioned previously, this factor accounts for inflows to the river below the USGS gage, as determined by HEC-RAS modeling completed as part of the MFL effort. Although the continuous recorders (HD-4 and HD-5) in the St. Marks River adjacent to the river cross section were not functioning on this date, HD-5 was back online within a few days, allowing some estimate of the expected tidal range during the April 11 data collection efforts. Given the freshwater inflows and the estimated tidal signal for this date, a date with similar tidal signal during the May 11 - 19 July 2017 calibration period was selected for comparison. The calibrated model was used to generate mass flux of water across the grid cells along the transect line. The comparison between the observed and modeled water mass fluxes was made to ensure that no additional considerations of wetland storage off the main river channel were needed to account for observed mass fluxes, and that the model as implemented accounts for the water mass fluxes moving through the river downstream of the confluence.

The measured water mass flux over a tidal cycle on April 11, 2017, is provided in Figure 27. Output from the model for water mass flux over a similar cycle on May 30, 2017, when combined flows at the St. Marks at Newport gage and the Wakulla gage were very similar, as were flows during the preceding 5 days, and with a similar tidal signal, is provided in Figure 28, for May 30, 2017 (day 19 of the model run). The range of simulated flows past this point in the river is very similar on May 30 to those observed on April 11. Interestingly, the simulated flows across this location on the river on May 11 (Figure 29) are even more similar to those measured on April 11.

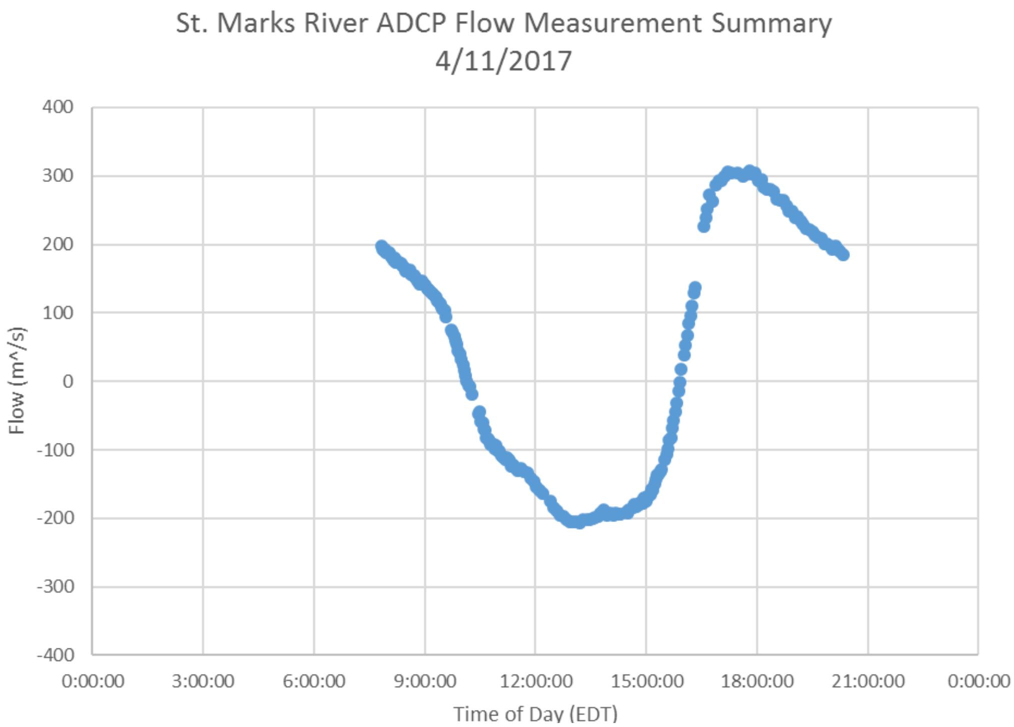

Figure 27. **Flow past cross-river transect between HD-4 and HD-5 measured on April 11, 2017 (from ATM, 2017a).**

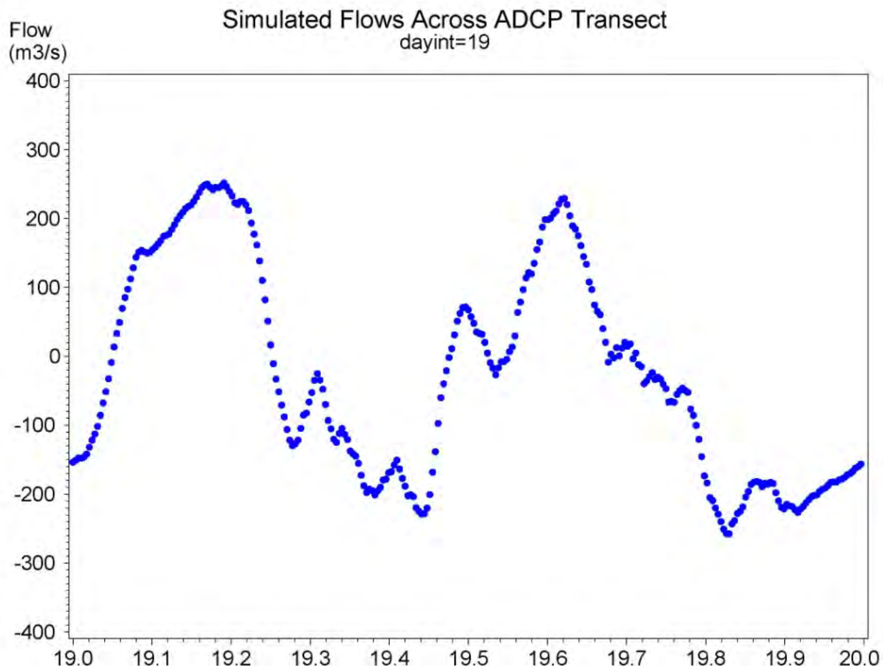

Figure 28. **Flow past cross-river transect between HD-4 and HD-5 modeled on May 30, 2017.**

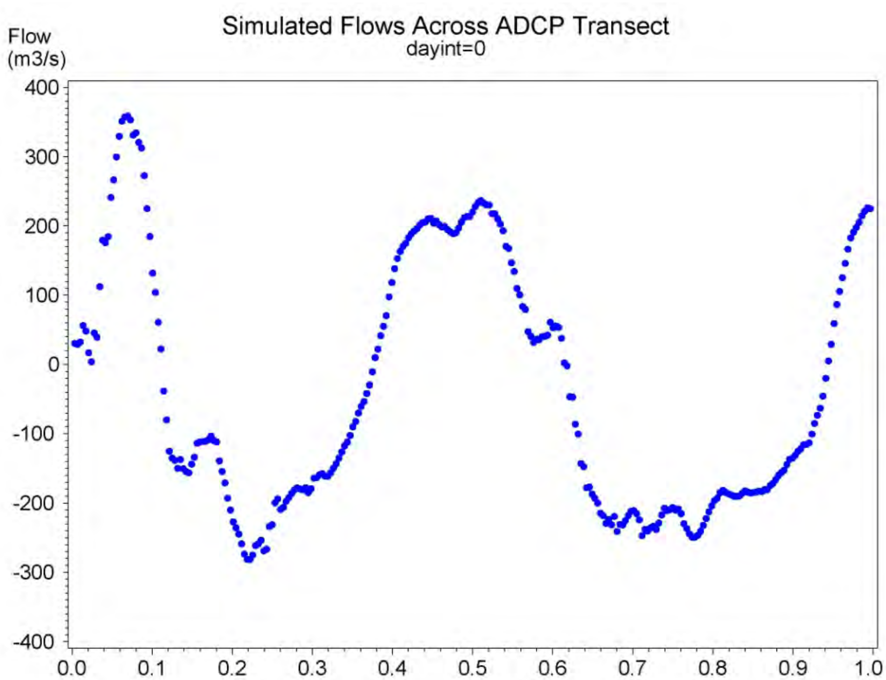

Figure 29. **Flow past cross-river transect between HD-4 and HD-5 modeled on May 11, 2017.**

Vertical profile data were collected along the axis of the St. Marks River and the Wakulla River during May 2016 - April 2017. No overlap occurred between the profile data collection dates and dates when sufficient data existed for calibration (11 May 2017 - 19 July 2017). However, examination of the gaged flows at the St. Marks Newport location during the profile data collection and during the calibration period found several events when similar flows occurred (Table 4). For those sites below the confluence (SM-1 through SM-8, as seen if Figure 26), the selection of comparable dates was based on the combined flows from the St. Marks Newport gage and the Wakulla gage. The matched profile and calibration period data were identified by a Group ID (Table 4) to aid in tracking events.

The following steps were taken to arrive at matched sets of observed and simulated profile data, to facilitate evaluation of the model's ability to appropriately simulate the vertical salinity distributions observed:

- Gaged flows were examined for dates when the profile data were collected, as well as for the preceding day, and days from the calibration period with similar current and preceding days' flows were selected.
- This provided a subset of the days on which profile data were collected which were matched with calibration period dates, when flows on dates of profile data collection matched relatively well the flows on specific dates during the calibration period.
- The time of the profile data collected was compared against the nearest-in-time high tide signal, and the time difference with this high tide was noted.
- The time of day for selection of the simulated data was accomplished by examining the timing of the nearest-in-time simulated high tide signal for the selected calibrated day for comparison, and the simulated vertical salinity profile data at each sampling site was selected with the same separation in timing as in the observed data.
- Vertical profiles of the paired observed and simulated salinity data at each site were plotted and compared, as provided in Attachment 2.

The results of the matching effort are provided in Table 4, which includes the flows during both the profile sampling events and the calibration period, and the dates associated with each as selected based on the matched flows. The profile sites in the table are those within the model domain, with each site assigned to a specific model grid cell for comparison. The 12 events represent only those profile sampling events for which reasonable flow matches were found during the calibration period.

Table 4. Match of profile data with calibration period model output. Empty cells indicate data not used for matching, based on locations of profile sites being matched.					
Profile Date: Sites Sampled	**Newport Gaged Flow (cfs)**	**Newport + Wakulla Gaged Flow (cfs)**	**Calibration Period Date**	**Newport Gaged Flow (cfs)**	**Newport + Wakulla Gaged Flow (cfs)**
18 May 2016:	17May16: 419	17May16: 1056	05 June 2017	04Jun17: 417	04Jun17: 1053
SM-1 thru SM-8, SM-12 thru SM-18	18May16: 424	18May16: 1107		05Jun17: 416	05Jun17: 1066
14 June 2016:		13Jun16: 1718	18 June 2017		17Jun17: 1718
SM-1 thru SM-8		14Jun16: 1633			18Jun17: 1681
15 June 2016:	14Jun16: 839		14 June 2017	13Jun17: 892	
SM-9 thru SM-18	15Jun16: 800			14Jun17: 817	
06 July 2016:	05Jul16: 558		02 July 2017	01Jul17: 555	
SM-9 thru SM-18	06Jul16: 551			02Jul17: 528	
07 July 2016:		06Jul16: 1102	30 May 2017		29May17: 1085
SM-1 thru SM-8		07Jul16: 1088			30May17: 1011
16 August 2016:		15Aug16: 1736	18 Jun 2017		17Jun17: 1719
SM-1 thru SM-8		16Aug16: 1640			18Jun17: 1673
17 August 2016:	16Aug16: 615		29 June 2017	28Jun17: 618	
SM-9 thru SM-18	17Aug16: 596			29Jun17: 600	
12 January 2017:		11Jan17: 1726	17 June 2017		16Jun17: 1751
SM-1 thru SM-8		12Jan17: 1696			17Jun17: 1719
13 January 2017:	12Jan17: 599		01 July 2017	30Jun17: 581	
SM-11 thru SM-18	13Jan17: 575			01Jul17: 555	
15 February 2017:	14Feb17: 604		30 June 2017	29Jun17: 600	
SM-9 thru SM-18	15Feb17: 595			30Jun17: 581	
28 March 2017:		27Mar17: 895	19 May 2017		18May17: 895
SM-1 thru SM-8		28Mar17: 923			19May17: 932
29 March 2017:	28Mar17: 413		03 June 2017	02Jun17: 411	
SM-1 thru SM-18	29Mar17: 411			03Jun17: 401	

When comparing the vertical profile plots provided in Attachment 2, it is important to note that although the 2-day flows are similar for the observed and simulated date periods, the actual tidal elevations and salinity conditions at the mouth of the river are not, and may be very dissimilar. Differences in the nearest-in-time high tide elevations ranged from 0.6 ft higher to 1.0 ft lower on the calibration dates than on the matched profile collected dates, so that the comparison of measured and simulated profiles are not expected to result in exact matches. Rather, this evaluation provides insight into the appropriateness of the modeled responses in salinity given similar freshwater inflows.

As shown in Attachment 2, some of the comparisons are in extremely good agreement, as shown on pages A2-2 - A2-16 and A2-53 - A2-60. Other events (pages A2-17 - A2-24 and A2-25 - A2-34) show somewhat lower simulated salinity values than those in the matched observed profile, while in some cases the simulated profiles show somewhat higher salinity than in the matched profile data (pages A2-45 - A2-52; A2-71 - A2-78; A2-97 - A2-104). For some of the matched events, both the observed data and the simulated data show very little salinity at the sites (pages A2-35 - A2-44; A2-61 - A2-70; A2-79 - A2-89; A2-105 - A2-112). It is evident from these comparisons that the model often simulates very similar vertical salinity profiles compared to observed profiles for similar flow environments.

Based on the model's ability to simulate water surface elevations, salinity, temperature, and mass flux in the lower river, the hydrodynamic model is considered appropriately calibrated to evaluate the responses in the river to spring flow reduction scenarios in support of MFL development. The next step in the model testing process, provided in the next Section, is to perform sensitivity analysis, and to evaluate the effects of three spring flow reduction percentages on salinity distributions during the calibration period, which will provide direction for the subsequent development of MFL scenarios.

4 Sensitivity Analysis and Preliminary Spring Flow Reduction Scenarios

This section presents the results of a sensitivity analysis of the calibrated hydrodynamic model to perturbations is a selected model parameter, and provides the results of the impacts on a set of Water Resource Values (WRVs) of preliminary spring flow reduction scenarios applied during the calibration period. The information provided by the sensitivity analysis provides an understanding of the model's responsiveness to the selected parameterization, and the results of the preliminary spring flow reduction scenarios serves as guidance in selection of scenarios for evaluation as part of the next step in this MFL determination.

4.1 Sensitivity Analysis

During hydrodynamic model calibration, it was found that the model was especially responsive to the roughness coefficient, a measure of the frictional effects of the river bottom on resultant flows, water surface elevations, and salinity transport. This is not surprising, as the river bottom data show differences in roughness, as represented by relatively small-scale changes in bathymetry, between the St. Marks River upstream of the confluence and that region downstream of the confluence extending to the mouth and offshore. Similarly, it is expected, based on our previous experience in modeling of rivers containing significant levels of submerged aquatic vegetation, that the Wakulla River portion of the model domain is a different regime with respect to bottom roughness characteristics as well. The roughness coefficient is included in the input file "DXDY.INP", and is specific to each model grid cell. Therefore, during calibration efforts, three different roughness coefficients were put in place in three different sections of the system; within the Wakulla River upstream of the confluence, the St. Marks River upstream of the confluence, and the St. Marks River downstream of the confluence. These spatial differences in roughness coefficients (frictional effects) enabled more accurate calibration of both water level and salinity characteristics within the system.

A relatively low coefficient was used for the river downstream of the confluence, $zrough = 0.001$. This is indicative of relatively smoothly changing bottom elevations, without much disruption of water movement due to interaction with the bottom. Within the St. Marks River upstream of the confluence, a value of $zrough = 0.020$ was used, indicating more rapid spatial changes in bathymetry. In the Wakulla River upstream of the confluence, the value $zrough = 0.040$ was used, to incorporate the effects of submerged aquatic vegetation on the flow. Examination of the bathymetry employed in the model (see Figures 2-4) supports these assignments, as the river downstream of the confluence shows relatively small bathymetry changes over much longer spatial scales that in the Wakulla and St. Marks rivers upstream of the confluence, and the Wakulla River shows a relatively constant wide river channel with relatively low variability in bottom elevations, in contrast to the St. Marks River upstream of the confluence, where a high degree of vertical variability in bottom elevations is found on relatively small spatial scales in both the cross-channel and along-channel directions.

For the sensitivity analysis scenarios, the calibrated model DXDY.INP file was revised so that the entire system was represented with one roughness coefficient for each scenario. Two sensitivity runs were completed, for comparison of WRV metrics to those from the calibrated model:

- Scenario A: zrough = 0.001 over the entire model domain; and
- Scenario B: zrough = 0.030 over the entire model domain.

The effects of the sensitivity analysis were quantified as the effects on the WRVs being evaluated for the MFL, including the following, all applied to the region in the St. Marks River upstream of the confluence:

- Volume of water ≤0.5 ppt, ≤5 ppt, and each 1 ppt increment between (≤1 ppt, ≤2 ppt, ≤3 ppt, ≤4 ppt);
- Bottom area for the same salinity regimes; and
- Shoreline length for the same salinity regimes.

The results of this analysis are provided in Tables 5 and 6. Table 5 provides the median of the daily average WRVs for the period May 11, 2017 - July 19, 2017 (the calibration period), while Table 6 provides the average of the daily average WRVs for the same period.

As shown in Table 5, the reduction of the roughness coefficient to *zrough* = 0.001 over the entire system results in a decline in the volume and bottom area for each of the salinity classes as compared to the calibrated (baseline) model. For this period, the median of the average daily condition for the shoreline length includes the entire shoreline of the domain upstream of the confluence, so no changes in shoreline length for each salinity zone resulted from the roughness coefficient variation. Conversely, the increase in the roughness coefficient to *zrough* = 0.030 over the entire system resulted in an increase in the volume and bottom area for each of the salinity classes as compared to the calibrated model. This indicates restriction in downstream movement of freshwater as the roughness increases, as expected.

These results point to the need, realized during the initial calibration effort, to make use of the best available information and experienced professional judgment when developing a calibrated model for a system extending over a spatially heterogeneous bathymetric domain. Final calibration was not reached until the effects of the various bottom types was considered in the model development, and these sensitivity analysis results provide an indication of how important this consideration is in this system.

Table 6 provides similar information based on the average of the average daily conditions, and shows similar results to those in Table 5.

Table 5. WRVs from calibrated model and sensitivity analysis scenarios, based on median of daily average values (5/11/17-7/19/17), St. Marks River upstream of confluence.						
Scenario	**Volume ≤0.5 ppt (m^3)**	**% Reduction**	**Bottom Area ≤0.5 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤0.5 ppt (m)**	**% Reduction**
Baseline	1,531,377		400,230		17,112	
Z=0.001	1,406,598	8.15	353,799	11.60	17,112	0.00
Z=0.030	1,590,279	-3.85	435,664	-8.85	17,112	0.00
Scenario	**Volume ≤1.0 ppt (m^3)**	**% Reduction**	**Bottom Area ≤1.0 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤1.0 ppt (m)**	**% Reduction**
Baseline	1,567,966		423,083		17,112	
Z=0.001	1,517,875	3.19	387,525	8.40	17,112	0.00
Z=0.030	1,598,246	-1.93	435,664	-2.97	17,112	0.00
Scenario	**Volume ≤2.0 ppt (m^3)**	**% Reduction**	**Bottom Area ≤2.0 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤2.0 ppt (m)**	**% Reduction**
Baseline	1,589,135		435,664		17,112	
Z=0.001	1,565,465	1.49	416,385	4.43	17,112	0.00
Z=0.030	1,599,238	-0.64	435,664	0.00	17,112	0.00
Scenario	**Volume ≤3.0 ppt (m^3)**	**% Reduction**	**Bottom Area ≤3.0 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤3.0 ppt (m)**	**% Reduction**
Baseline	1,592,940		435,664		17,112	
Z=0.001	1,570,799	1.39	435,259	0.09	17,112	0.00
Z=0.030	1,606,629	-0.86	435,664	0.00	17,112	0.00
Scenario	**Volume ≤4.0 ppt (m^3)**	**% Reduction**	**Bottom Area ≤4.0 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤4.0 ppt (m)**	**% Reduction**
Baseline	1,599,747		435,664		17,112	
Z=0.001	1,578,446	1.33	435,664	0.00	17,112	0.00
Z=0.030	1,606,873	-0.45	435,664	0.00	17,112	0.00
Scenario	**Volume ≤5.0 ppt (m^3)**	**% Reduction**	**Bottom Area ≤5.0 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤5.0 ppt (m)**	**% Reduction**
Baseline	1,601,137		435,664		17,112	
Z=0.001	1,588,174	0.81	435,664	0.00	17,112	0.00
Z=0.030	1,606,873	-0.36	435,664	0.00	17,112	0.00

Table 6. **WRVs from calibrated model and sensitivity analysis scenarios, based on average of daily average values (5/11/17-7/19/17), St. Marks River upstream of confluence.**

Scenario	Volume $\leq$0.5 ppt (m^3)	% Reduction	Bottom Area $\leq$0.5 ppt (m^2)	% Reduction	Shoreline Length $\leq$0.5 ppt (m)	% Reduction
Baseline	1,449,807		376,021		16,498	
Z=0.001	1,330,539	8.23	340,999	9.31	15,931	3.43
Z=0.030	1,517,450	-4.67	399,716	-6.30	16,766	-1.62
Scenario	**Volume $\leq$1.0 ppt (m^3)**	**% Reduction**	**Bottom Area $\leq$1.0 ppt (m^2)**	**% Reduction**	**Shoreline Length $\leq$1.0 ppt (m)**	**% Reduction**
Baseline	1,497,869		389,710		16,850	
Z=0.001	1,402,434	6.37	359,502	7.75	16,417	2.57
Z=0.030	1,554,642	-3.79	410,314	-5.29	17,065	-1.28
Scenario	**Volume $\leq$2.0 ppt (m^3)**	**% Reduction**	**Bottom Area $\leq$2.0 ppt (m^2)**	**% Reduction**	**Shoreline Length $\leq$2.0 ppt (m)**	**% Reduction**
Baseline	1,543,447		403,231		17,096	
Z=0.001	1,475,250	4.42	379,585	5.86	16,933	0.96
Z=0.030	1,582,216	-2.51	418,861	-3.88	17,112	-0.09
Scenario	**Volume $\leq$3.0 ppt (m^3)**	**% Reduction**	**Bottom Area $\leq$3.0 ppt (m^2)**	**% Reduction**	**Shoreline Length $\leq$3.0 ppt (m)**	**% Reduction**
Baseline	1,566,51		411,192		17,112	
Z=0.001	1,517,073	3.16	391,863	4.70	17,109	0.01
Z=0.030	1,595,612	-1.86	424,240	-3.17	17,112	0.00
Scenario	**Volume $\leq$4.0 ppt (m^3)**	**% Reduction**	**Bottom Area $\leq$4.0 ppt (m^2)**	**% Reduction**	**Shoreline Length $\leq$4.0 ppt (m)**	**% Reduction**
Baseline	1,580,713		416,883		17,112	
Z=0.001	1,543,913	2.33	401,520	3.69	17,112	0.00
Z=0.030	1,603,593	-1.45	428,563	-2.80	17,112	0.00
Scenario	**Volume $\leq$5.0 ppt (m^3)**	**% Reduction**	**Bottom Area $\leq$5.0 ppt (m^2)**	**% Reduction**	**Shoreline Length $\leq$5.0 ppt (m)**	**% Reduction**
Baseline	1,590,960		421,701		17,112	
Z=0.001	1,563,505	1.73	409,053	3.00	17,112	0.00
Z=0.030	1,608,510	-1.10	430,740	-2.14	17,112	0.00

4.2 Preliminary Flow Reduction Scenarios

Preliminary flow reduction scenarios were implemented for the calibration period to provide some idea of the likely magnitude of effects on WRVs of spring flow reductions for the MFL baseline period. The MFL baseline period has been developed under another Task Order (Janicki Environmental, 2018), and is being selected as a relatively long (25-month) period during which gaged St. Marks River flows are representative of long-term flow distributions. This preliminary spring flow reduction analysis provides guidance for selecting spring flow reduction scenarios for MFL evaluations.

The St. Marks River Rise spring discharge is estimated as the difference between the USGS gaged flow at Newport (02326900) and the flow measured above the St. Marks River swallet at Woodville (02326885). The spring discharge was determined for the 5/11/17-7/19/17 calibration period. The spring flow portion of the total gaged flow at Newport was then reduced by 10%, 20%, and 30% for the three scenarios evaluated here. The WRV metrics resulting from these spring flow reduction scenarios were then compared to those from the calibration run (used as the baseline for this preliminary evaluation).

The effects of the sensitivity analysis were quantified as the effects on the WRV metrics being evaluated, including the following, which were all applied to the region in the St. Marks River upstream of the confluence:

- Volume of water $\leq$0.5 ppt, $\leq$5 ppt, and each 1 ppt increment between ($\leq$1 ppt, $\leq$2 ppt, $\leq$3 ppt, and $\leq$4 ppt);
- Bottom area for the same salinity regimes; and
- Shoreline length for the same salinity regimes.

The results of this analysis are provided in Tables 7 and 8. Table 7 provides the median of the daily average WRVs for the baseline and each flow reduction scenario for the period 5/11/17-7/19/17 (the calibration period), while Table 8 provides the average of the daily average WRVs for the same period.

As shown in Table 7, showing the medians of the average daily WRVs, the reduction in spring flow results in a decline in the volume and bottom area for each of the salinity classes as compared to the calibrated (baseline) model. This effect is most pronounced for the lower salinity classes, with the changes in the $\leq$0.5 ppt WRVs the greatest. Reductions in WRVs increases with increasing spring flow reduction, as expected. However, even at 30% spring flow reduction, the greatest reduction in WRV is for the $\leq$0.5 ppt bottom area, at only 6.72%. Even at this high spring flow reduction, the WRV reduction is much less than 15%, an accepted and acknowledged limit for allowable reductions in WRV metrics. Similarly, in Table 8, which provides the average of the average daily WRVs, all reductions in WRVs associated with the 30% spring flow reduction result in less than a 15% change in habitat metrics.

Based on these findings, it is recommended that the initial spring flow reduction scenario aimed at establishing an MFL for the St. Marks River Rise be the 30% spring flow reduction run. This will provide information concerning the effects of a relatively high reduction in spring flow on the estuarine WRV metrics being evaluated.

Table 7. WRVs from calibrated model and spring flow reduction scenarios, based on median of daily average values (5/11/17-7/19/17), St. Marks River upstream of confluence.						
Scenario	**Volume ≤0.5 ppt (m^3)**	**% Reduction**	**Bottom Area ≤0.5 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤0.5 ppt (m)**	**% Reduction**
Baseline	1,531,377		400,230		17,112	
10%	1,505,847	1.67	391,868	2.09	17,112	0.00
20%	1,477,178	3.54	385,009	3.80	17,112	0.00
30%	1,451,410	5.22	373,347	6.72	17,112	0.00
Scenario	**Volume ≤1.0 ppt (m^3)**	**% Reduction**	**Bottom Area ≤1.0 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤1.0 ppt (m)**	**% Reduction**
Baseline	1,567,966		423,083		17,112	
10%	1,554,672	0.85	419,791	0.78	17,112	0.00
20%	1,548,719	1.23	411,070	2.84	17,112	0.00
30%	1,536,380	2.01	397,986	5.93	17,112	0.00
Scenario	**Volume ≤2.0 ppt (m^3)**	**% Reduction**	**Bottom Area ≤2.0 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤2.0 ppt (m)**	**% Reduction**
Baseline	1,589,135		435,664		17,112	
10%	1,579,087	0.63	432,679	0.69	17,112	0.00
20%	1,575,735	0.84	425,151	2.41	17,112	0.00
30%	1,570,058	1.20	422,433	3.04	17,112	0.00
Scenario	**Volume ≤3.0 ppt (m^3)**	**% Reduction**	**Bottom Area ≤3.0 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤3.0 ppt (m)**	**% Reduction**
Baseline	1,592,940		435,664		17,112	
10%	1,591,201	0.11	435,664	0.00	17,112	0.00
20%	1,588,926	0.25	435,664	0.00	17,112	0.00
30%	1,577,123	0.99	435,664	0.00	17,112	0.00
Scenario	**Volume ≤4.0 ppt (m^3)**	**% Reduction**	**Bottom Area ≤4.0 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤4.0 ppt (m)**	**% Reduction**
Baseline	1,599,747		435,664		17,112	
10%	1,595,362	0.27	435,664	0.00	17,112	0.00
20%	1,591,481	0.52	435,664	0.00	17,112	0.00
30%	1,589,432	0.64	435,664	0.00	17,112	0.00
Scenario	**Volume ≤5.0 ppt (m^3)**	**% Reduction**	**Bottom Area ≤5.0 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤5.0 ppt (m)**	**% Reduction**
Baseline	1,601,137		435,664		17,112	
10%	1,599,478	0.10	435,664	0.00	17,112	0.00
20%	1,598,236	0.18	435,664	0.00	17,112	0.00
30%	1,593,217	0.49	435,664	0.00	17,112	0.00

Table 8. WRVs from calibrated model and spring flow reduction scenarios, based on average of daily average values (5/11/17-7/19/17), St. Marks River upstream of confluence.						
Scenario	**Volume ≤0.5 ppt (m^3)**	**% Reduction**	**Bottom Area ≤0.5 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤0.5 ppt (m)**	**% Reduction**
Baseline	1,449,807		376,021		16,498	
10%	1,427,195	1.56	368,540	1.99	16,392	0.64
20%	1,402,887	3.24	361,675	3.82	16,262	1.43
30%	1,375,748	5.11	354,264	5.79	16,121	2.28
Scenario	**Volume ≤1.0 ppt (m^3)**	**% Reduction**	**Bottom Area ≤1.0 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤1.0 ppt (m)**	**% Reduction**
Baseline	1,497,869		389,710		16,850	
10%	1,480,425	1.16	384,211	1.41	16,766	0.50
20%	1,460,870	2.47	377,566	3.12	16,672	1.06
30%	1,438,004	4.00	370,045	5.05	16,569	1.67
Scenario	**Volume ≤2.0 ppt (m^3)**	**% Reduction**	**Bottom Area ≤2.0 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤2.0 ppt (m)**	**% Reduction**
Baseline	1,543,447		403,231		17,096	
10%	1,530,403	0.85	398,419	1.19	17,073	0.14
20%	1,515,944	1.78	393,340	2.45	17,046	0.29
30%	1,499,432	2.85	387,891	3.80	17,007	0.52
Scenario	**Volume ≤3.0 ppt (m^3)**	**% Reduction**	**Bottom Area ≤3.0 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤3.0 ppt (m)**	**% Reduction**
Baseline	1,566,517		411,192		17,111	
10%	1,556,966	0.61	407,527	0.89	17,111	0.00
20%	1,545,861	1.32	403,173	1.95	17,111	0.00
30%	1,533,415	2.11	398,204	3.16	17,111	0.01
Scenario	**Volume ≤4.0 ppt (m^3)**	**% Reduction**	**Bottom Area ≤4.0 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤4.0 ppt (m)**	**% Reduction**
Baseline	1,580,713		416,883		17,112	
10%	1,573,777	0.44	413,661	0.77	17,112	0.00
20%	1,565,817	0.94	409,988	1.65	17,112	0.00
30%	1,555,967	1.57	406,191	2.56	17,112	0.00
Scenario	**Volume ≤5.0 ppt (m^3)**	**% Reduction**	**Bottom Area ≤5.0 ppt (m^2)**	**% Reduction**	**Shoreline Length ≤5.0 ppt (m)**	**% Reduction**
Baseline	1,590,960		421,701		17,112	
10%	1,585,426	0.35	418,908	0.66	17,112	0.00
20%	1,579,558	0.72	416,231	1.30	17,112	0.00
30%	1,572,180	1.18	412,497	2.18	17,112	0.00

5 Summary and Conclusions

This report provided a summary of the development, calibration, and application of a hydrodynamic model developed for the tidal portions of the St. Marks and Wakulla rivers. This included the following:

- Development of the hydrodynamic model grid system;
- Development of input datasets for the EFDC hydrodynamic model calibration;
- Development and calibration of the EFDC hydrodynamic model; and
- Performance of sensitivity analysis and implementation of preliminary spring flow reduction scenarios during the calibration period to guide future potential MFL scenarios definition.

The model extends offshore within the Gulf of Mexico and up the St. Marks and Wakulla rivers to the US 98 bridge crossings. The EFDC model was used to simulate the hydrodynamics, including the water levels, currents, salinity, and temperature. The model simulations for the calibration extended from May 11, 2017, to July 19, 2017.

The model has one open boundary condition approximately 3 km offshore of the mouth of the St. Marks River. For the model calibration, the offshore water level boundary conditions were developed from measured water levels at the mouth (HD-5) using boundary matching techniques. The offshore salinity boundary conditions were derived from the daily maxima of the continuous salinity measured at the mouth (at HD-5).

Graphical and statistical comparisons of the simulated versus measured water levels were presented at five locations along the system, at each of the continuous recorders (HD-1 through HD-5). These locations provided data at the mouth (HD-5), at a point mid-way between the confluence and the mouth (HD-4), at the confluence (HD-3), and at the upstream model limits within each river (HD-1 in the St. Marks River and HD-2 in the Wakulla River). The results showed good agreement both graphically and statistically to the measured data.

Graphical and statistical comparisons of the simulated and measured salinity and temperature were presented. This included bottom and surface data at the mouth (HD-5) and at the location mid-way between the mouth and the confluence (HD-4), and bottom data at the confluence (HD-3). Data collected at the upstream sites (HD-1 in the St. Marks River and HD-2 in the Wakulla River) were used as boundary conditions for input, and so were not used for comparison. The comparisons showed that the model captured the timing and magnitude of the responses to the freshwater inflow on salinity intrusion and the distribution of the salinity between the stations.

Graphical comparisons of the simulated and measured time-dependent flow at a location between HD-4 and HD-5 were made, although the measured data were not collected during the calibration period. Dates during the calibration period when gaged flows were similar to those when the data were collected were identified, and the simulated data on those dates were compared to the measured data. The results showed good agreement between the measured and simulated flow magnitudes, phasing and characteristics.

Similarly, comparisons to observed salinity vertical profile data were made, although the measured data collection dates did not coincide with the calibration period dates. As for the flow comparison, dates during the calibration period when similar gaged flows existed as on the measured data collection dates were identified, and comparisons were made between the measured and simulated vertical salinity profiles at various locations along the St. Marks River, both upstream and downstream of the confluence. These comparisons often showed good agreement between the measured and simulated salinity vertical distributions, even though downstream tidal conditions were typically different during the comparison date pairs.

The calibrated hydrodynamic model was then utilized to perform a sensitivity analysis based on variations in the bottom roughness coefficient, found during the calibration period to be an important determinant of water and associated salt movement in the system. This effort pointed to the importance in recognizing and accounting for the varying bottom conditions within different regions of the system.

Finally, three preliminary spring flow reduction scenarios were completed using the calibration period, and comparisons made between the WRV metrics resulting from these scenarios and those from the calibration run (the baseline for this exercise). For the calibration period, it was found that a 30% spring flow reduction did not result in changes in WRV metrics by as much as 15%. The recommendation was made to initiate the next step of the MFL evaluation with a 30% spring flow reduction run over the 25-month baseline period.

6 References

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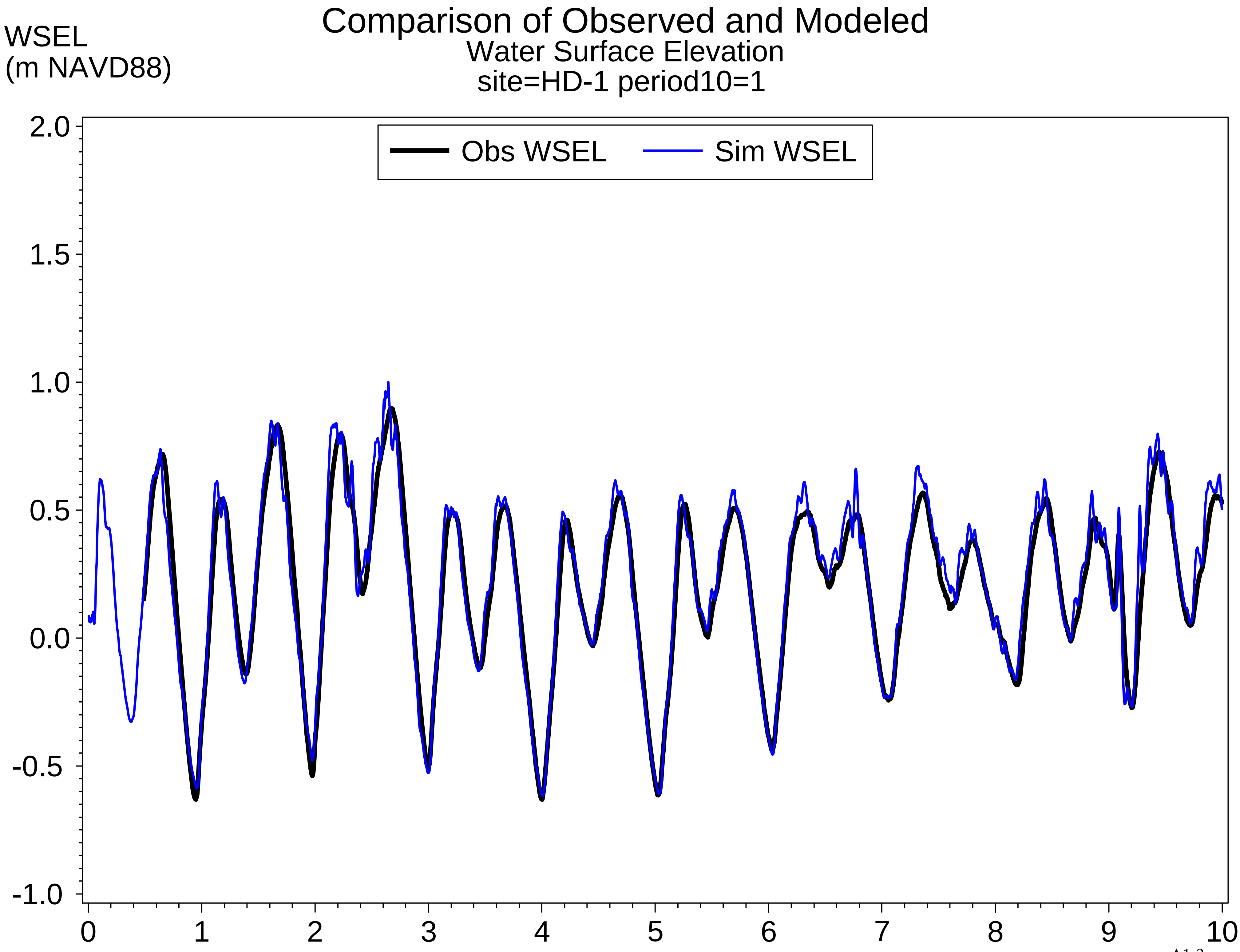
ATTACHMENT 1
TIME SERIES COMPARISONS OF SIMULATED AND OBSERVED DATA:
WATER SURFACE ELEVATION
SURFACE AND BOTTOM SALINITY
SURFACE AND BOTTOM TEMPERATURE



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(m NAVD88)
Comparison of Observed and Modeled
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Obs WSEL
Sim WSEL
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3
4
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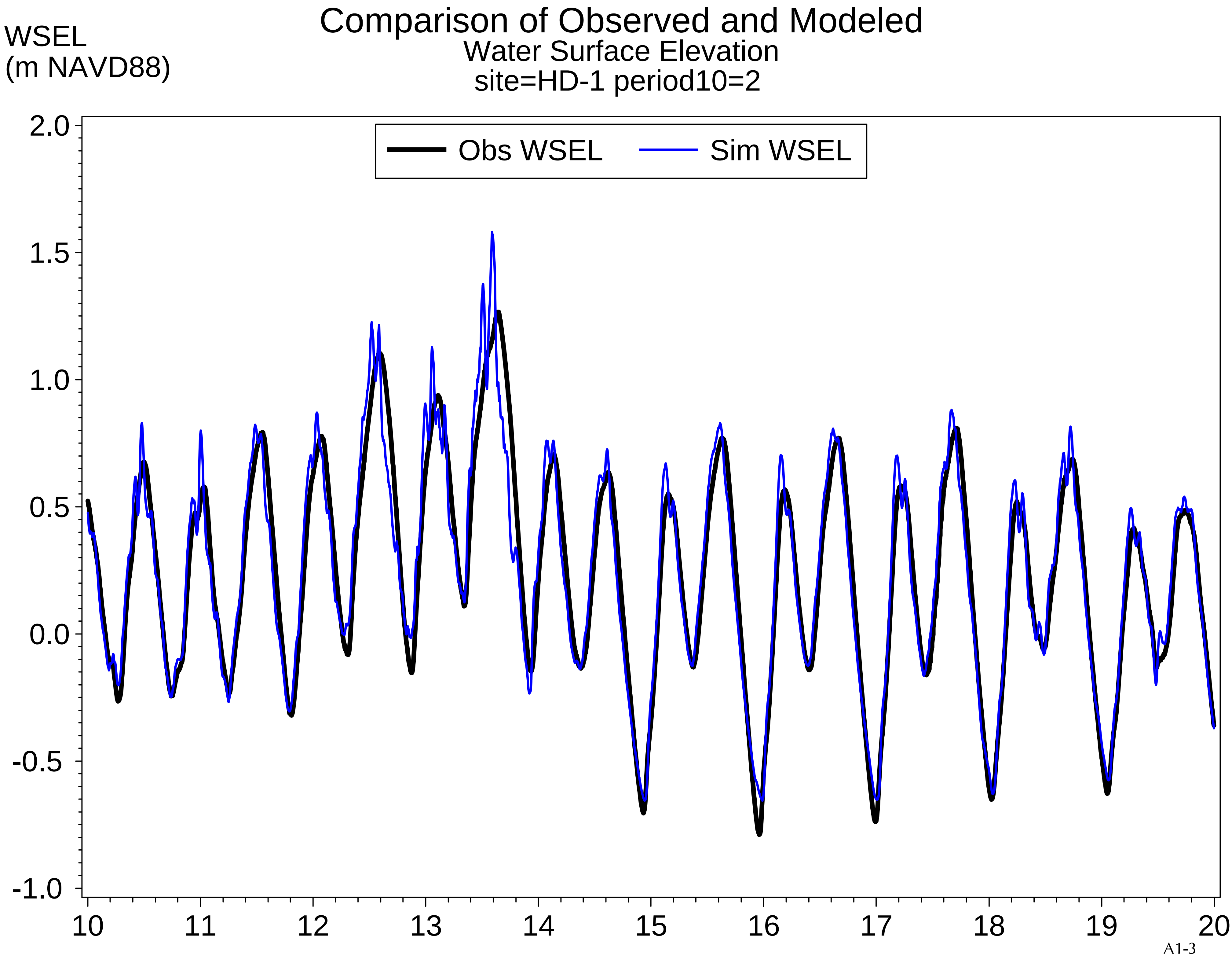
7
8
9
10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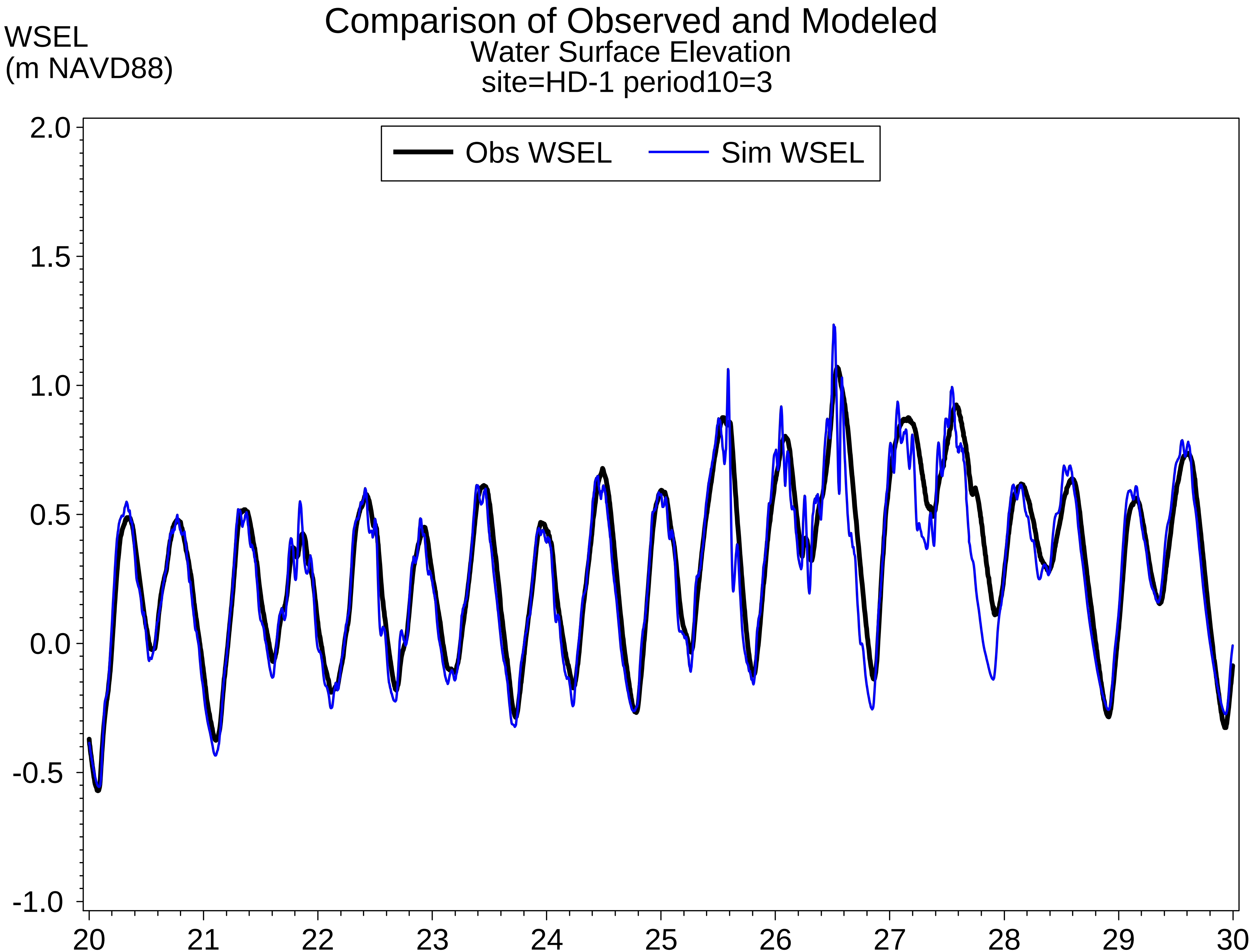
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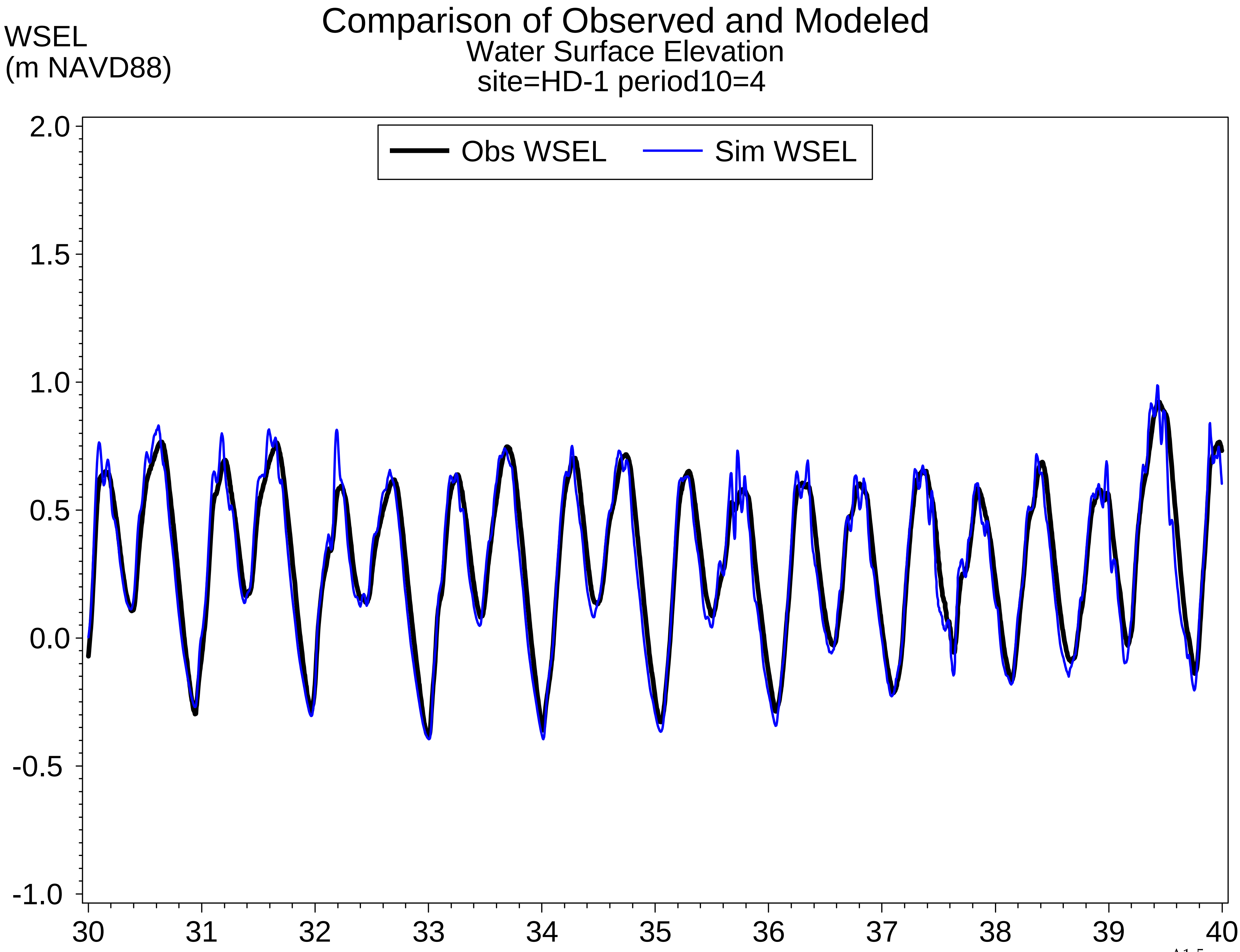

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0.0
-0.5
-1.0
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37
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40

Comparison of Observed and Modeled
Water Surface Elevation
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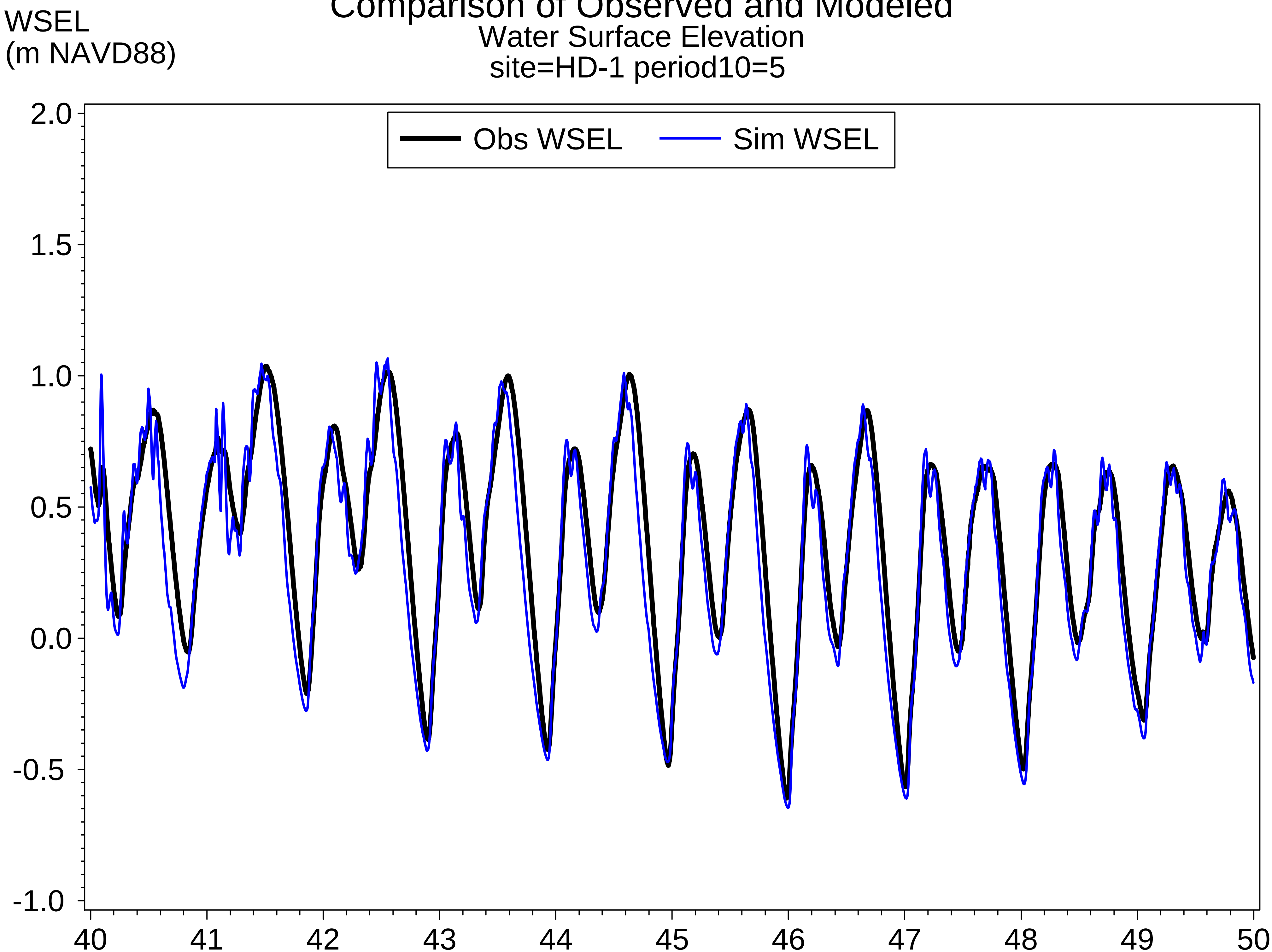

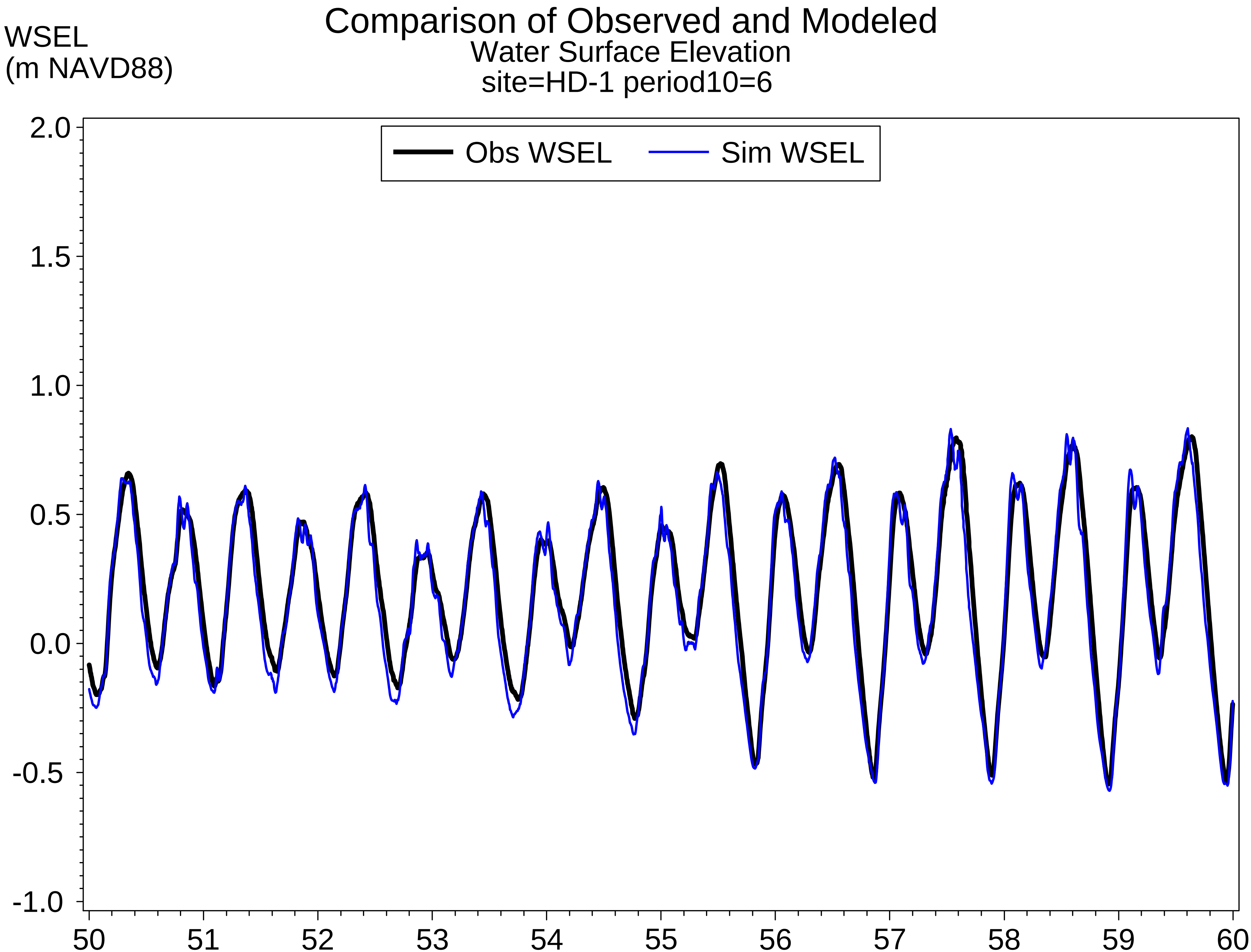
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Comparison of Observed and Modeled
Water Surface Elevation
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Sim WSEL
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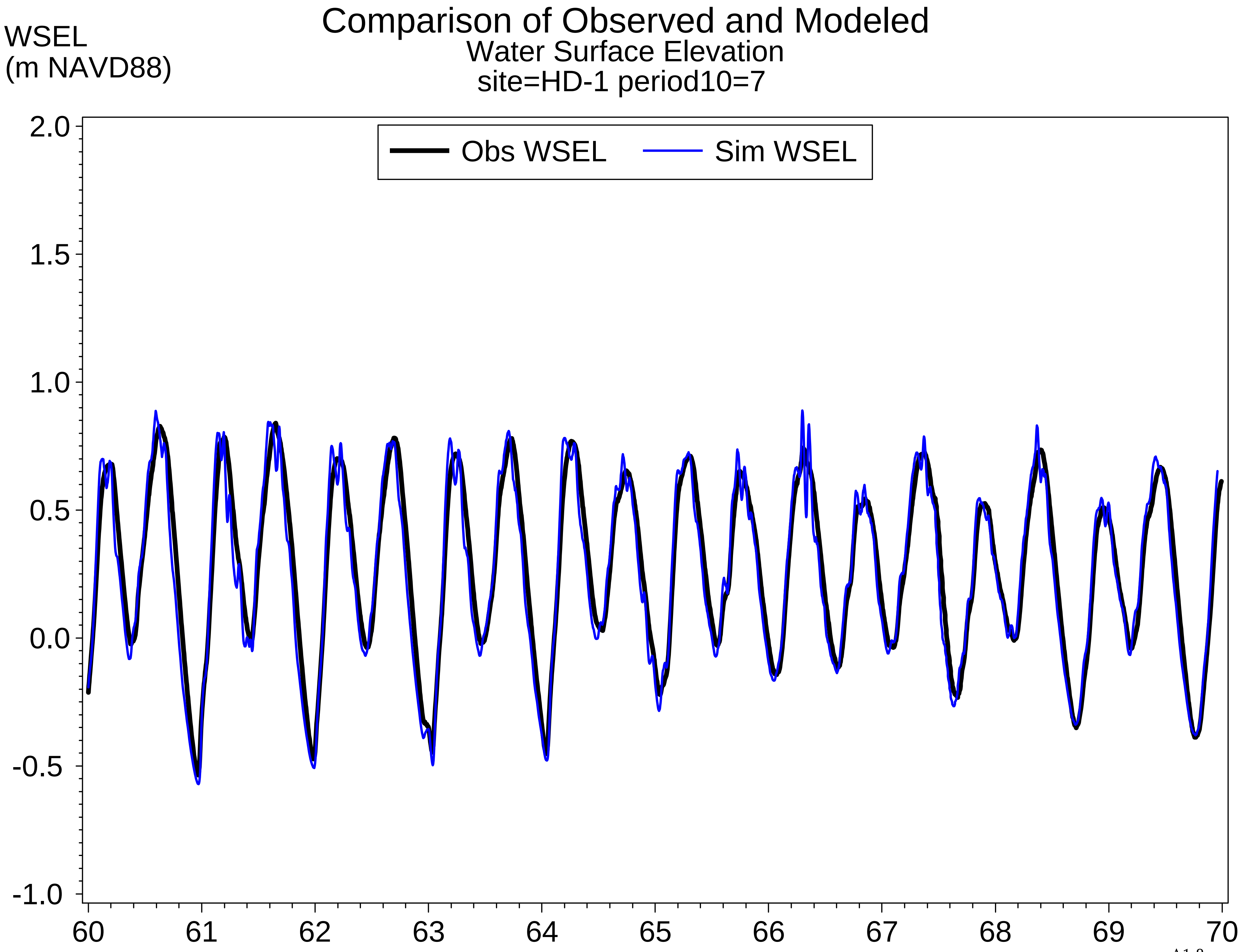

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Comparison of Observed and Modeled
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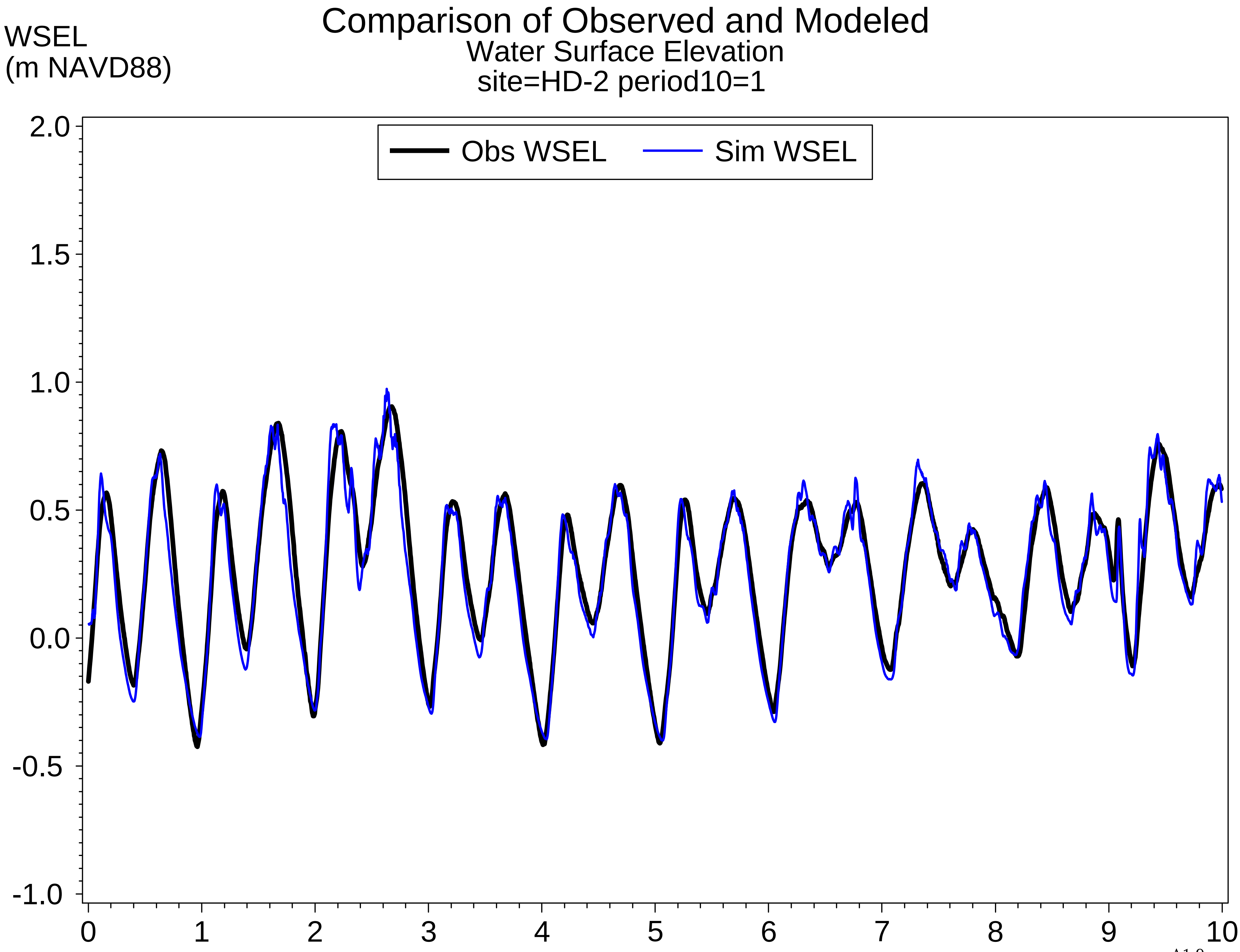
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Comparison of Observed and Modeled
Water Surface Elevation
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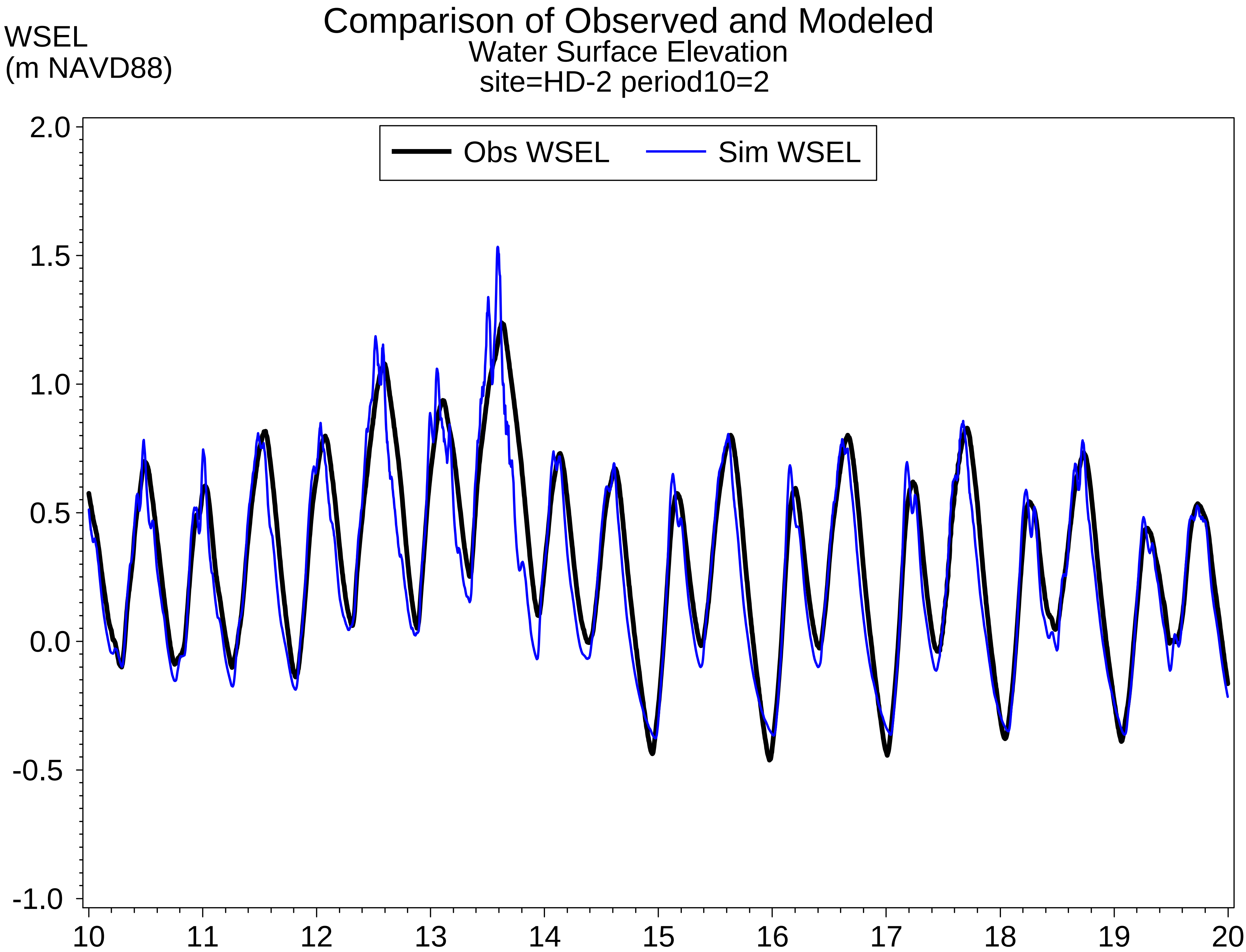
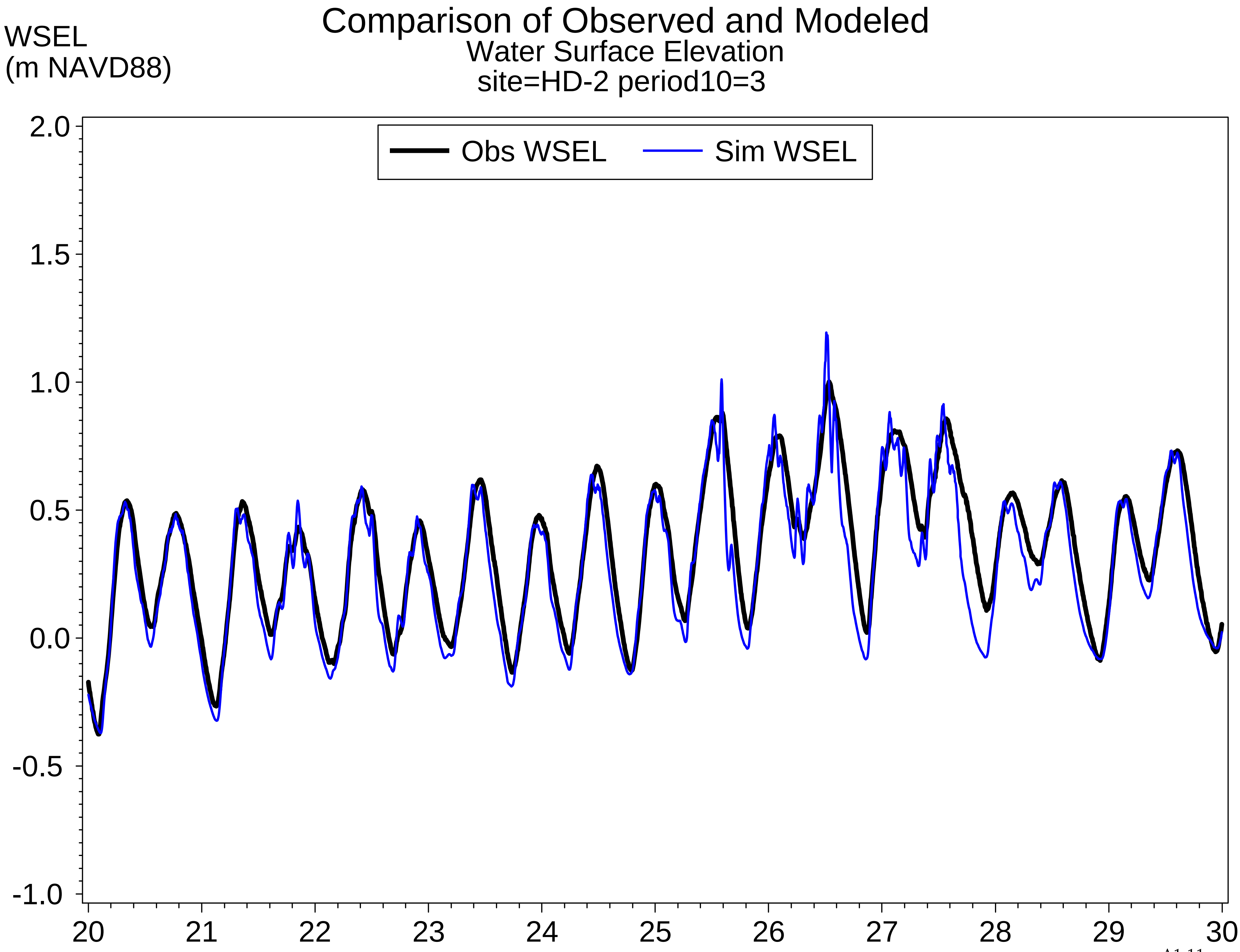
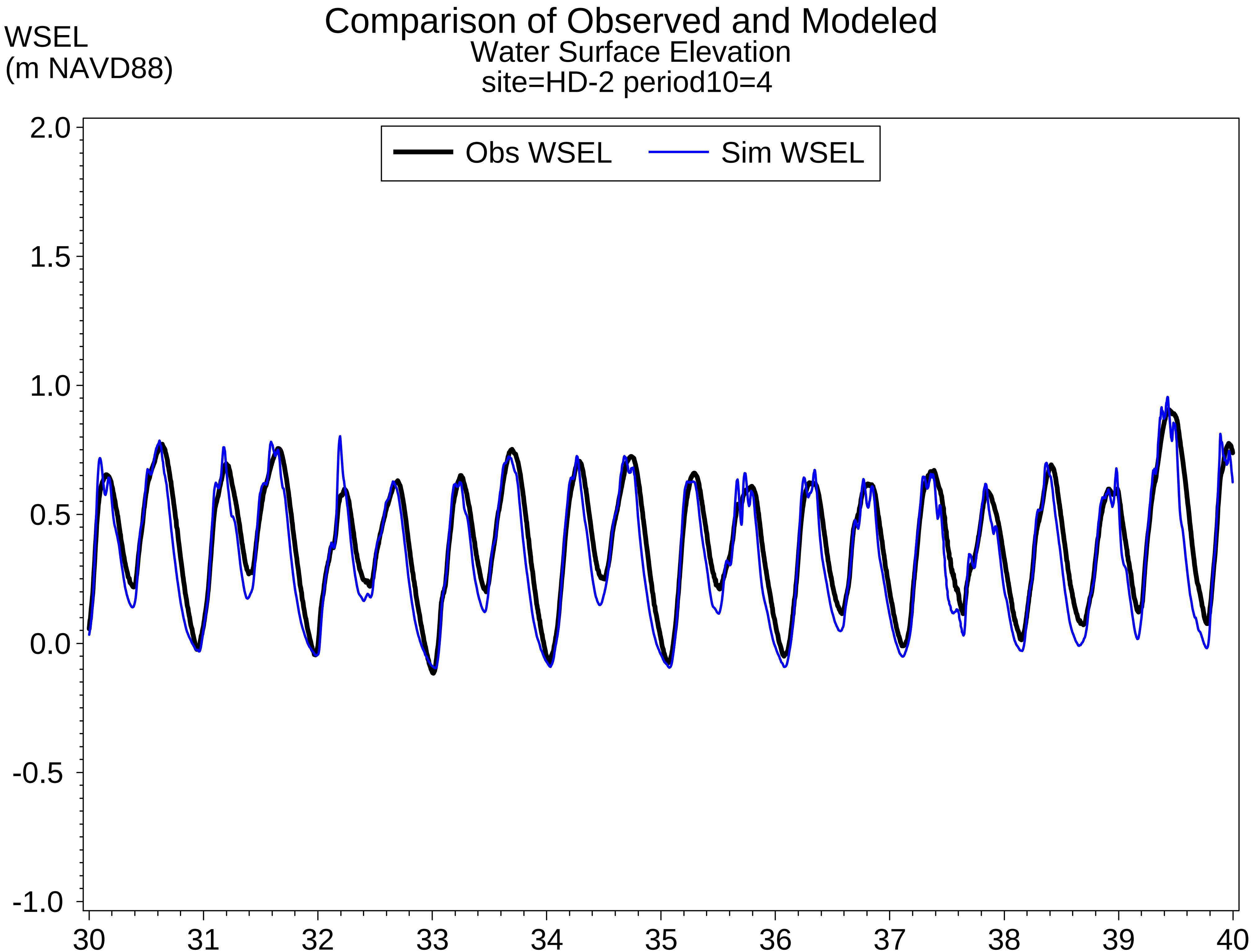
6
7
8
9
10

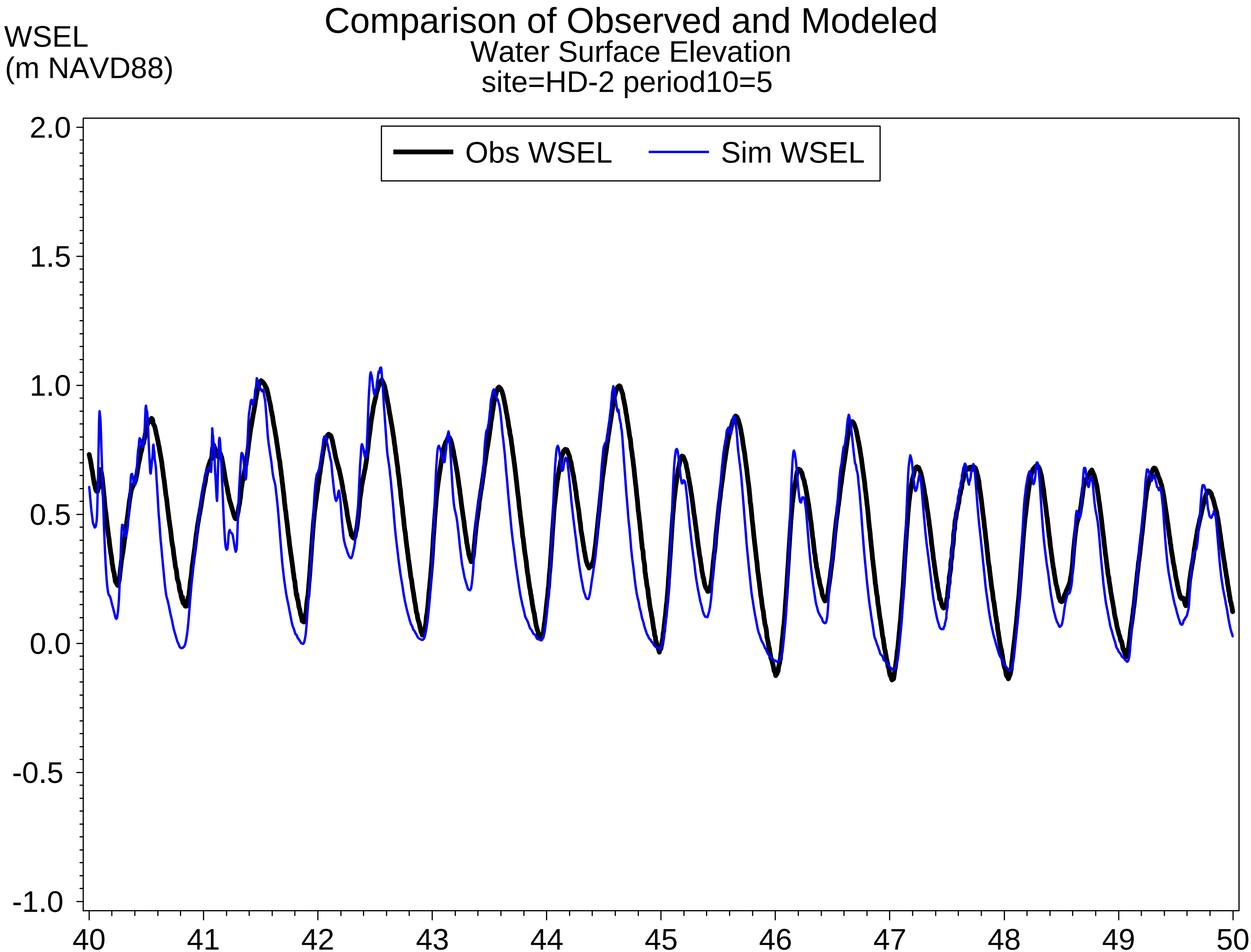


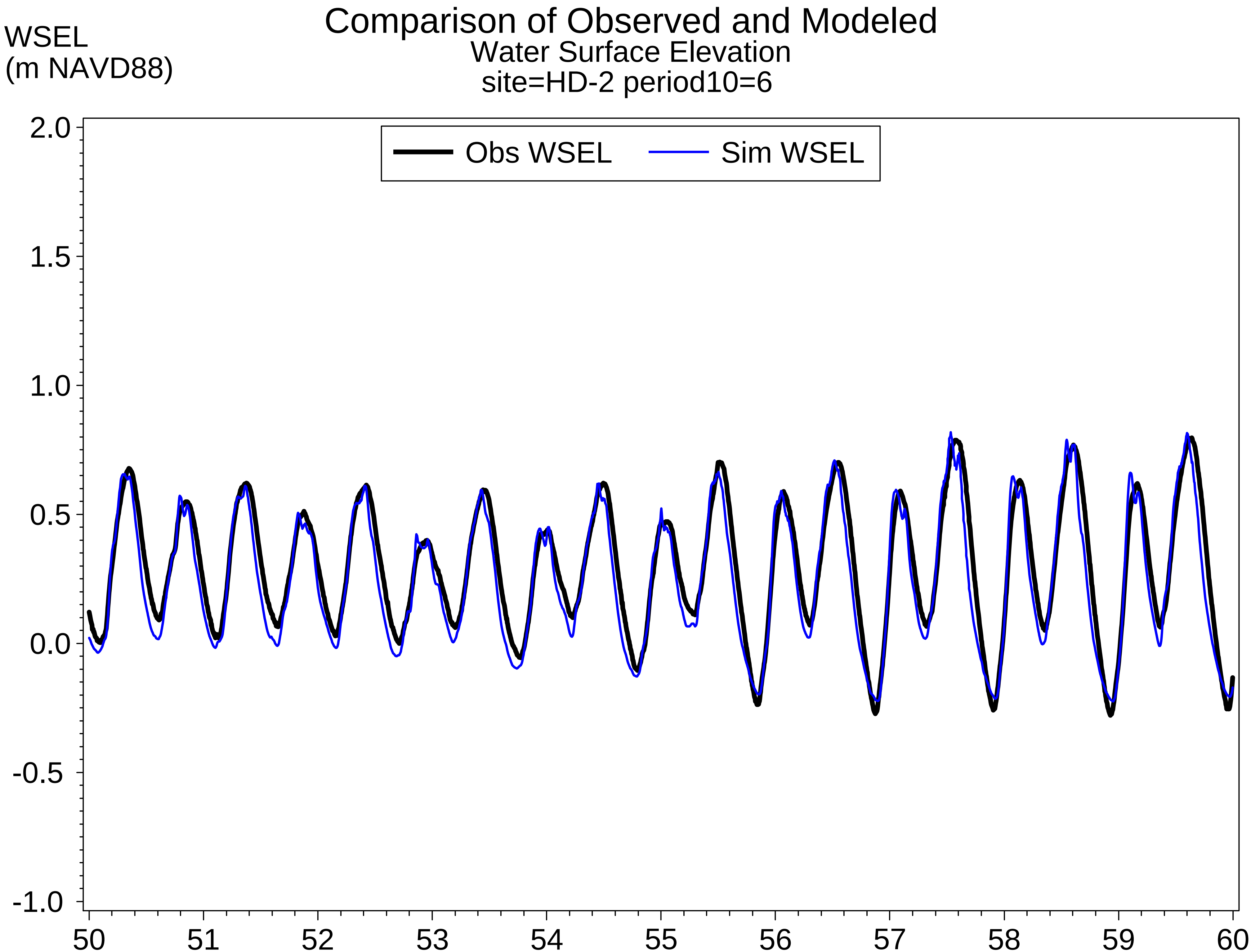
WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-2 period10=2
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
10
11
12
13
14
15
16
17
18
19
20



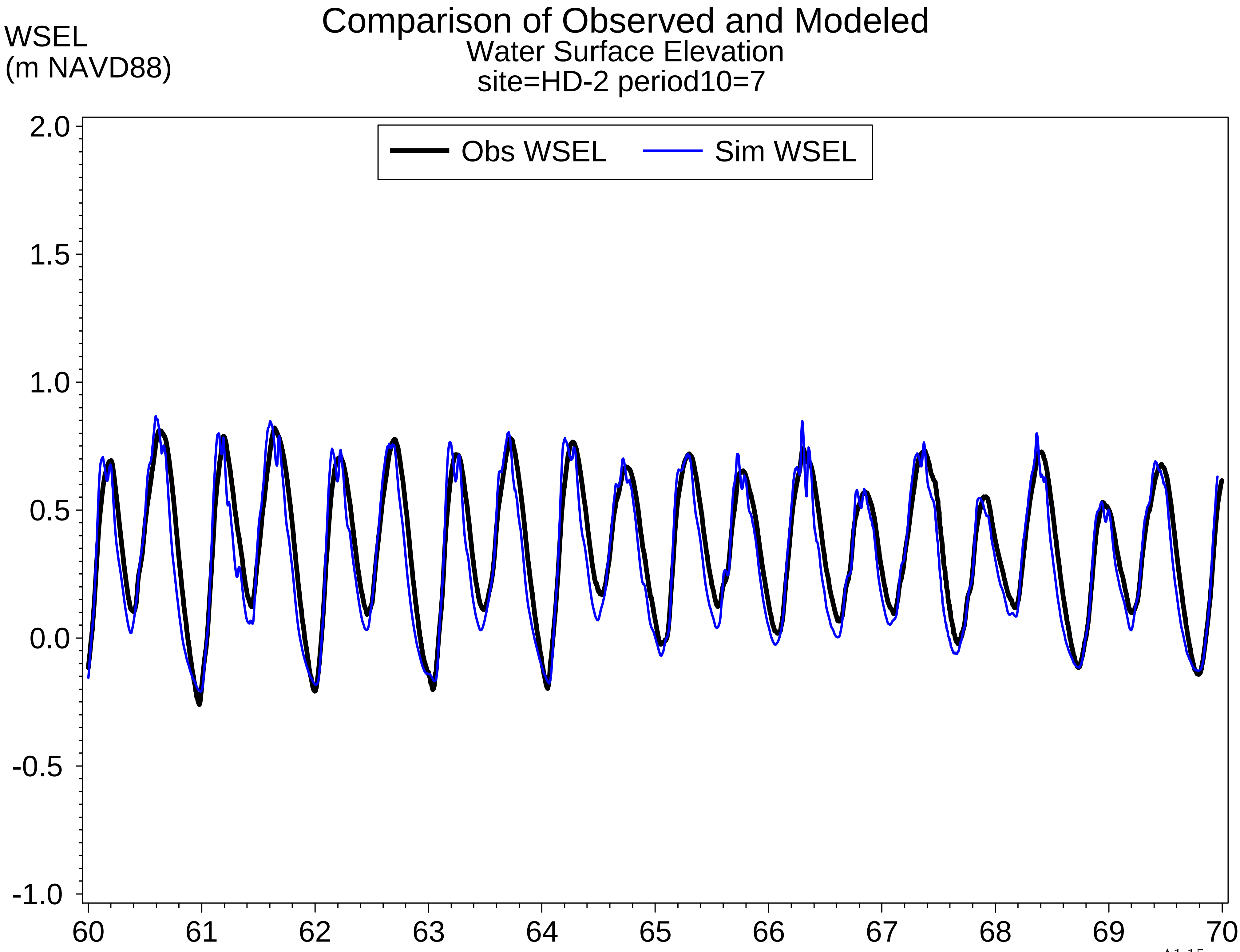
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-2 period10=3
WSEL
(m NAVD88)
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
20
21
22
23
24
25
26
27
28
29
30

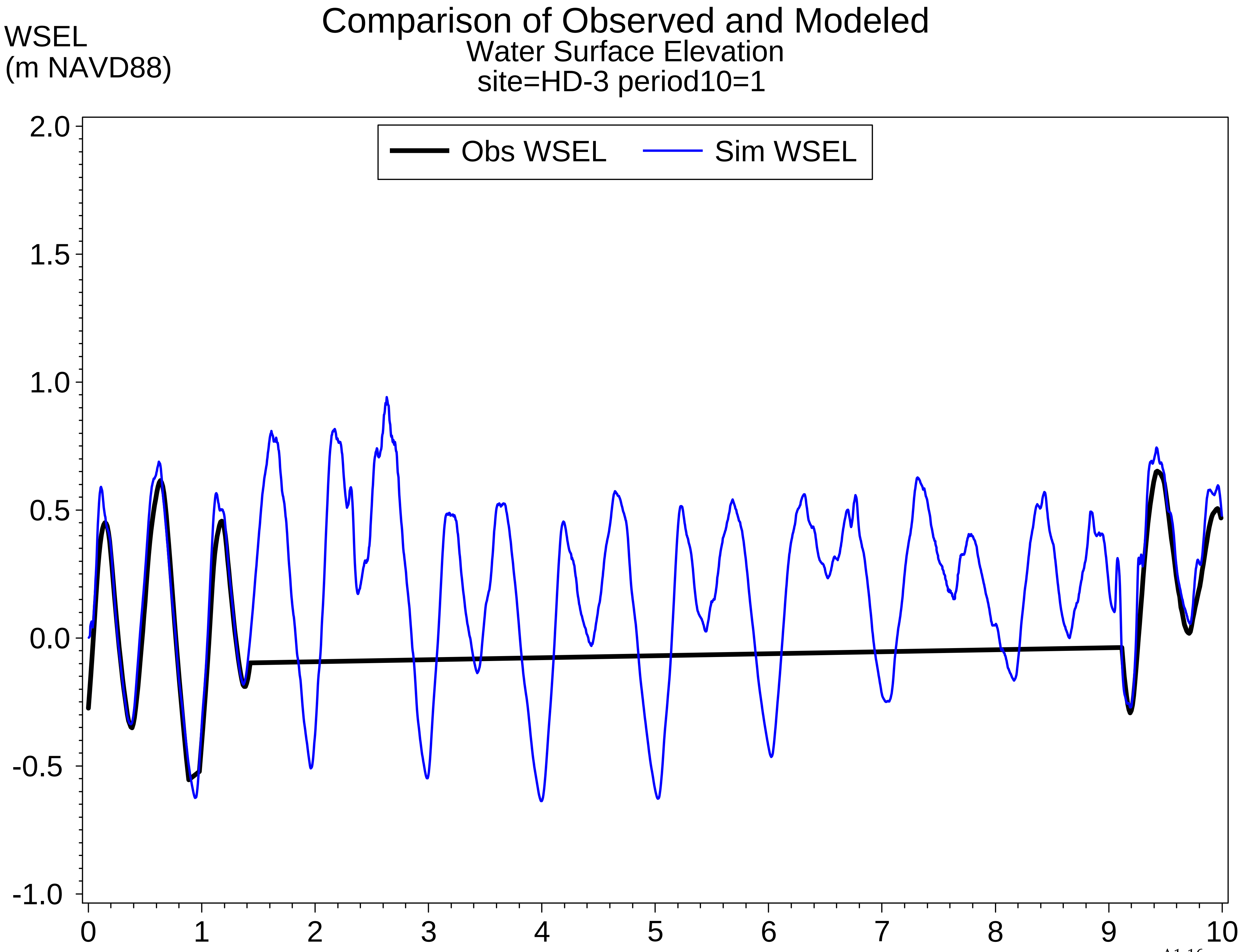

WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-2 period10=4
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
30
31
32
33
34
35
36
37
38
39
40


WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-2 period10=5
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
40
41
42
43
44
45
46
47
48
49
50

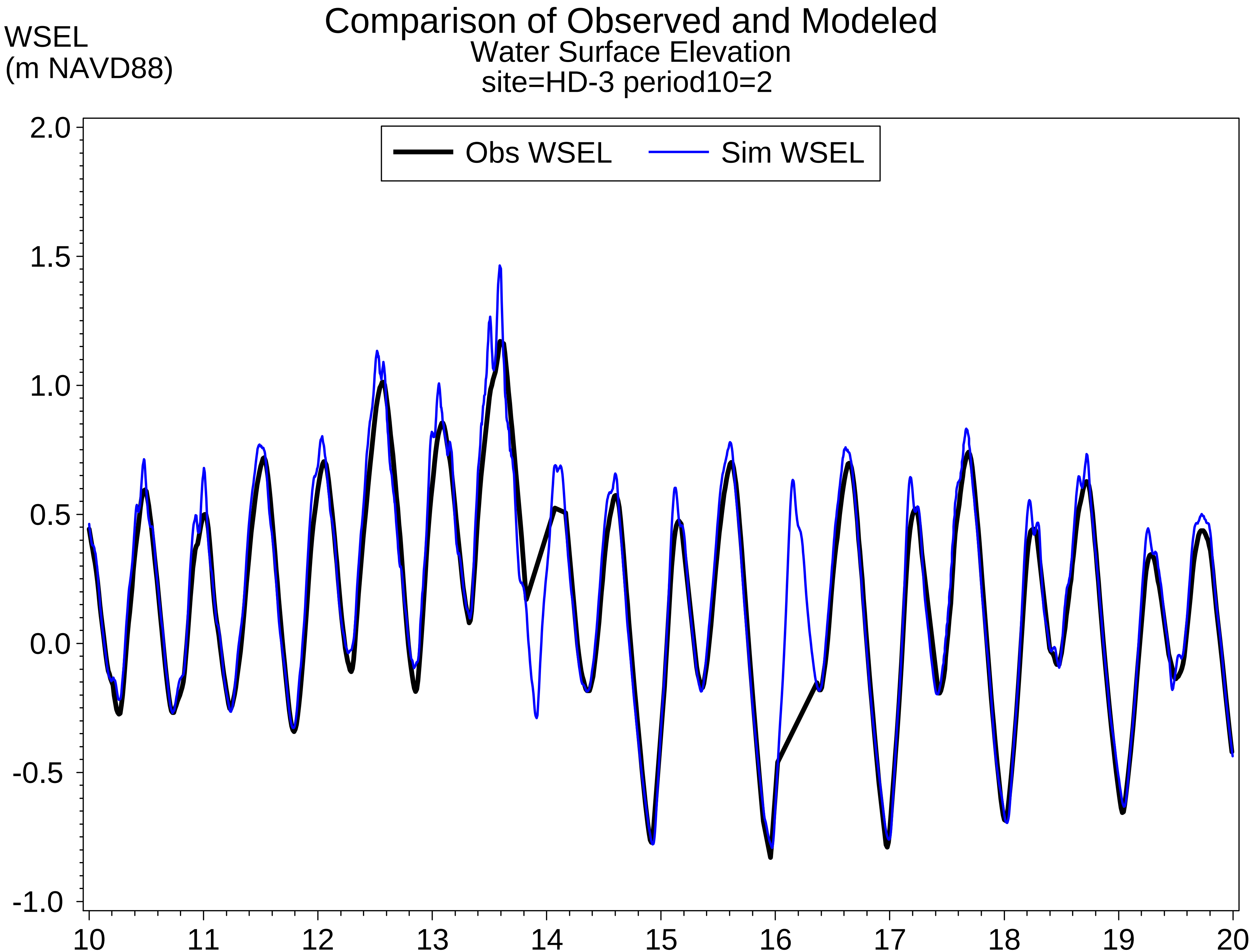


WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-2 period10=6
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
50
51
52
53
54
55
56
57
58
59
60

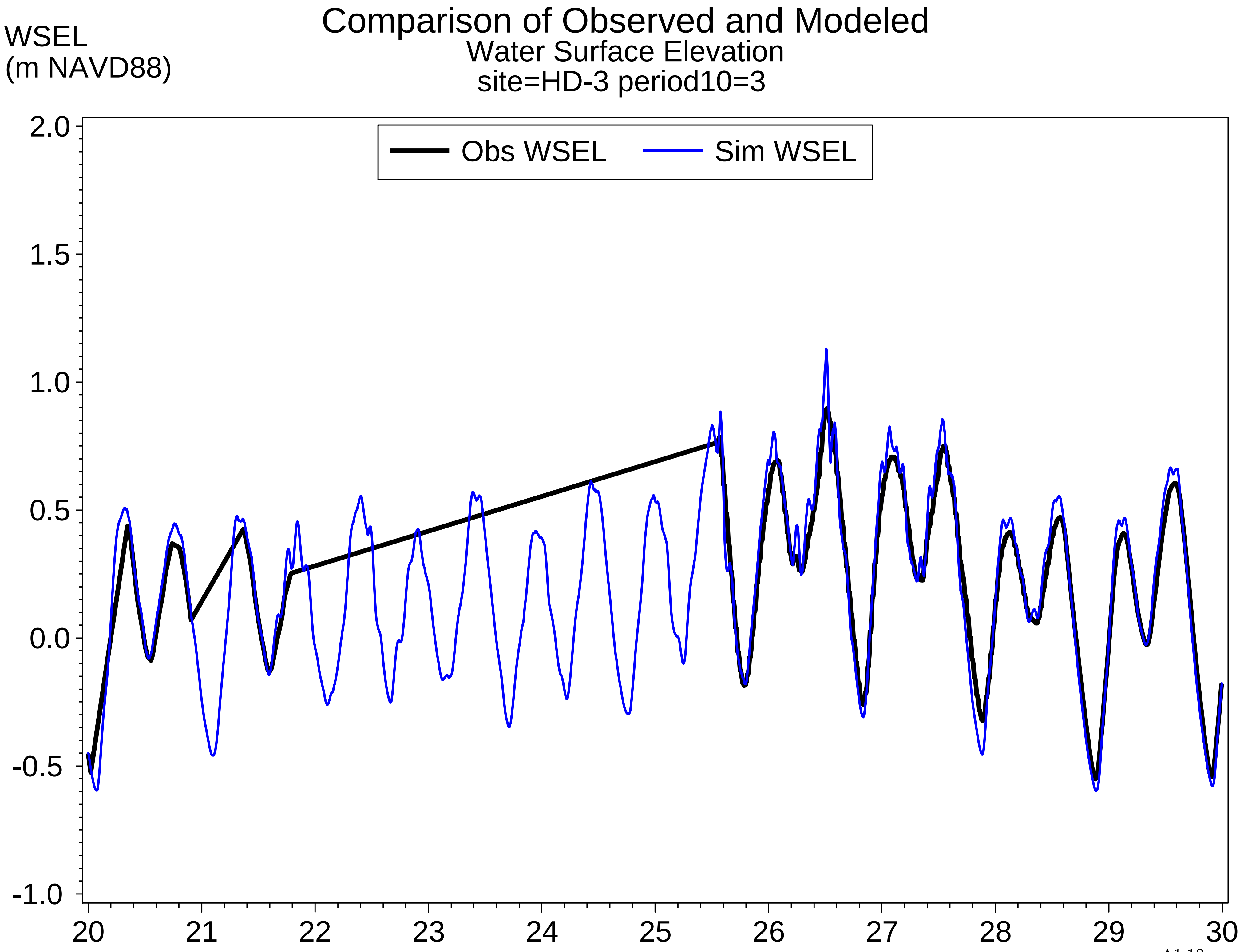

WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-2 period10=7
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
60
61
62
63
64
65
66
67
68
69
70


WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-3 period10=1
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
0
1
2
3
4
5
6
7
8
9
10

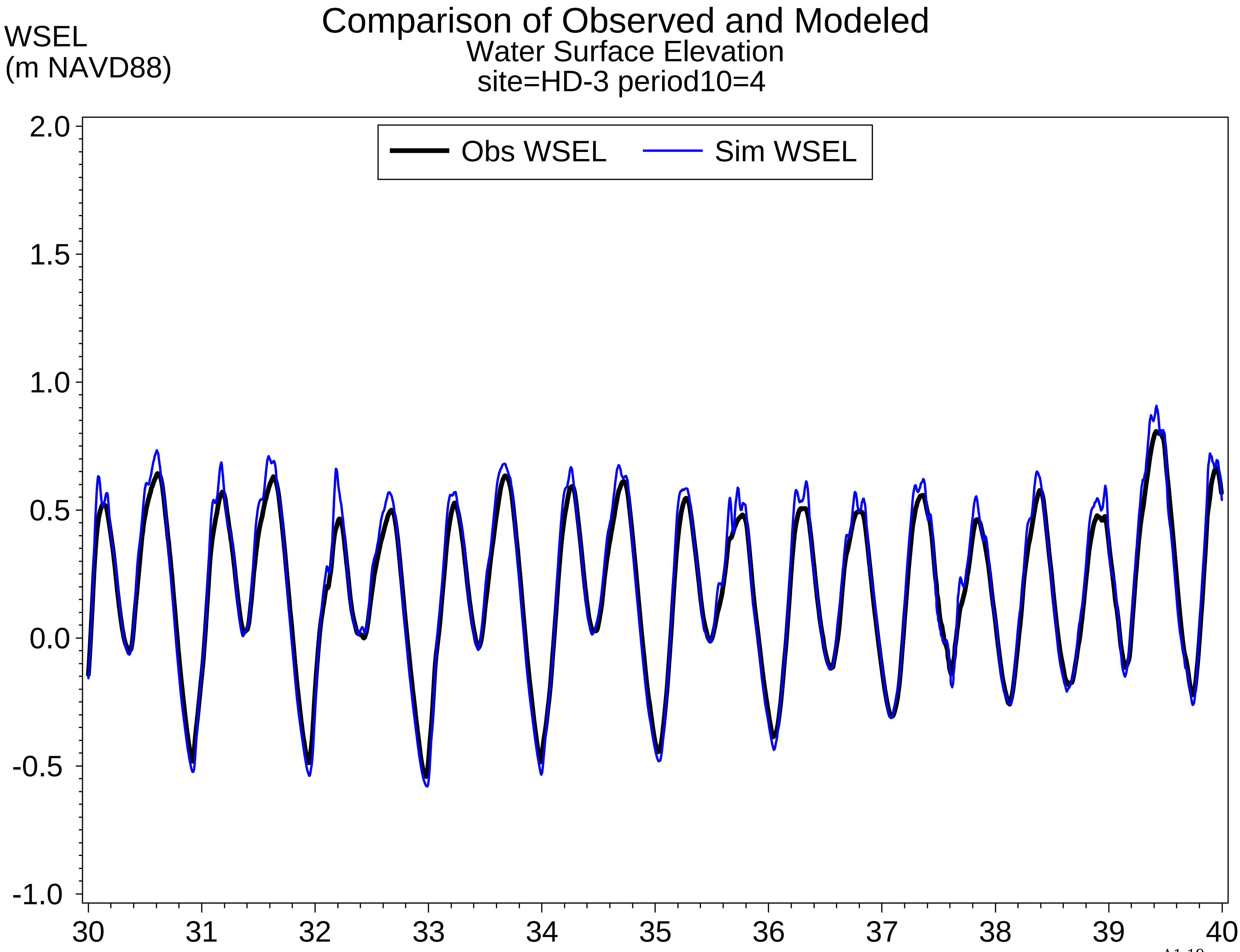
A1-16



Comparison of Observed and Modeled
Water Surface Elevation
site=HD-3 period10=2
WSEL
(m NAVD88)
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
10
11
12
13
14
15
16
17
18
19
20

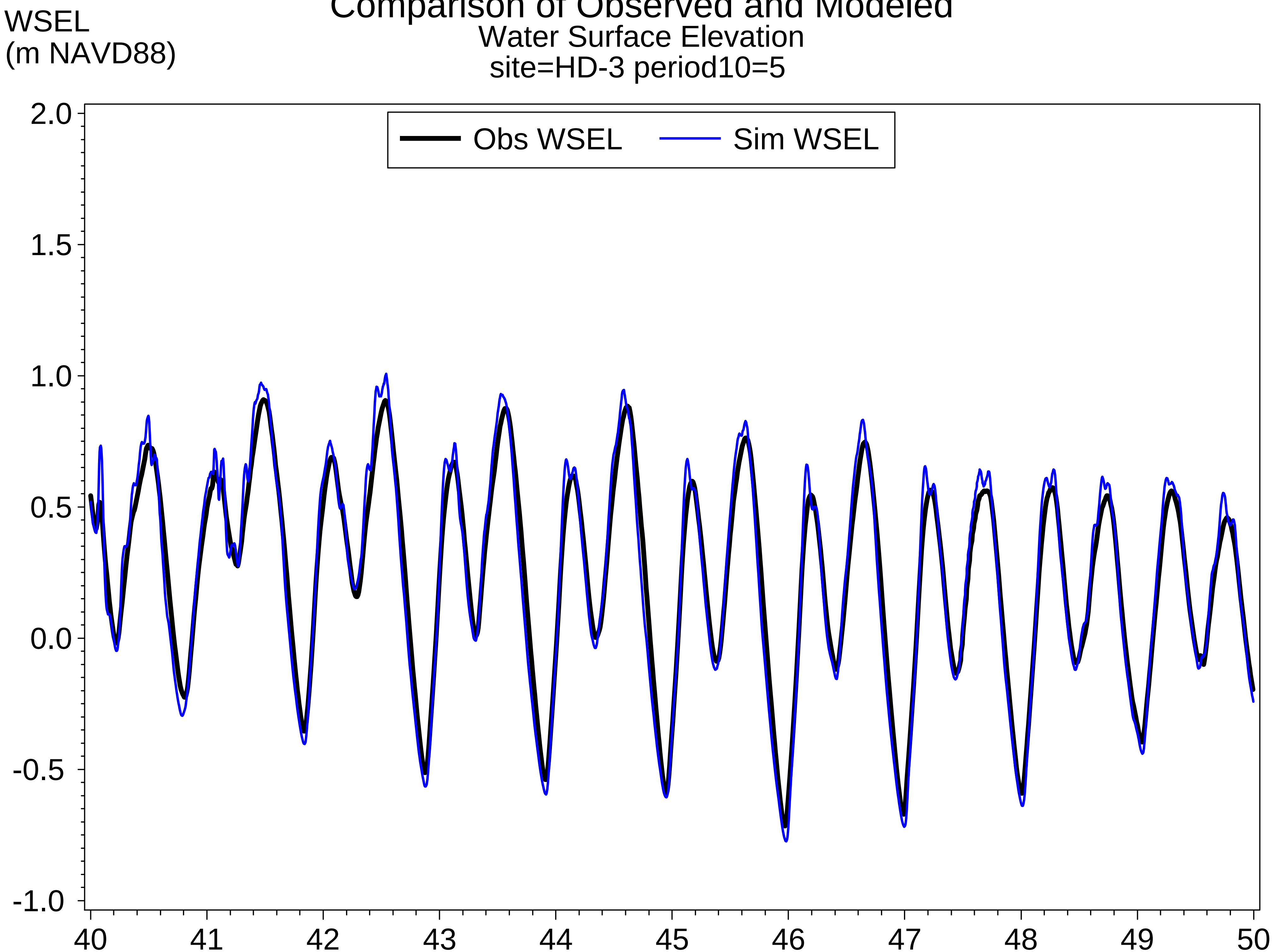


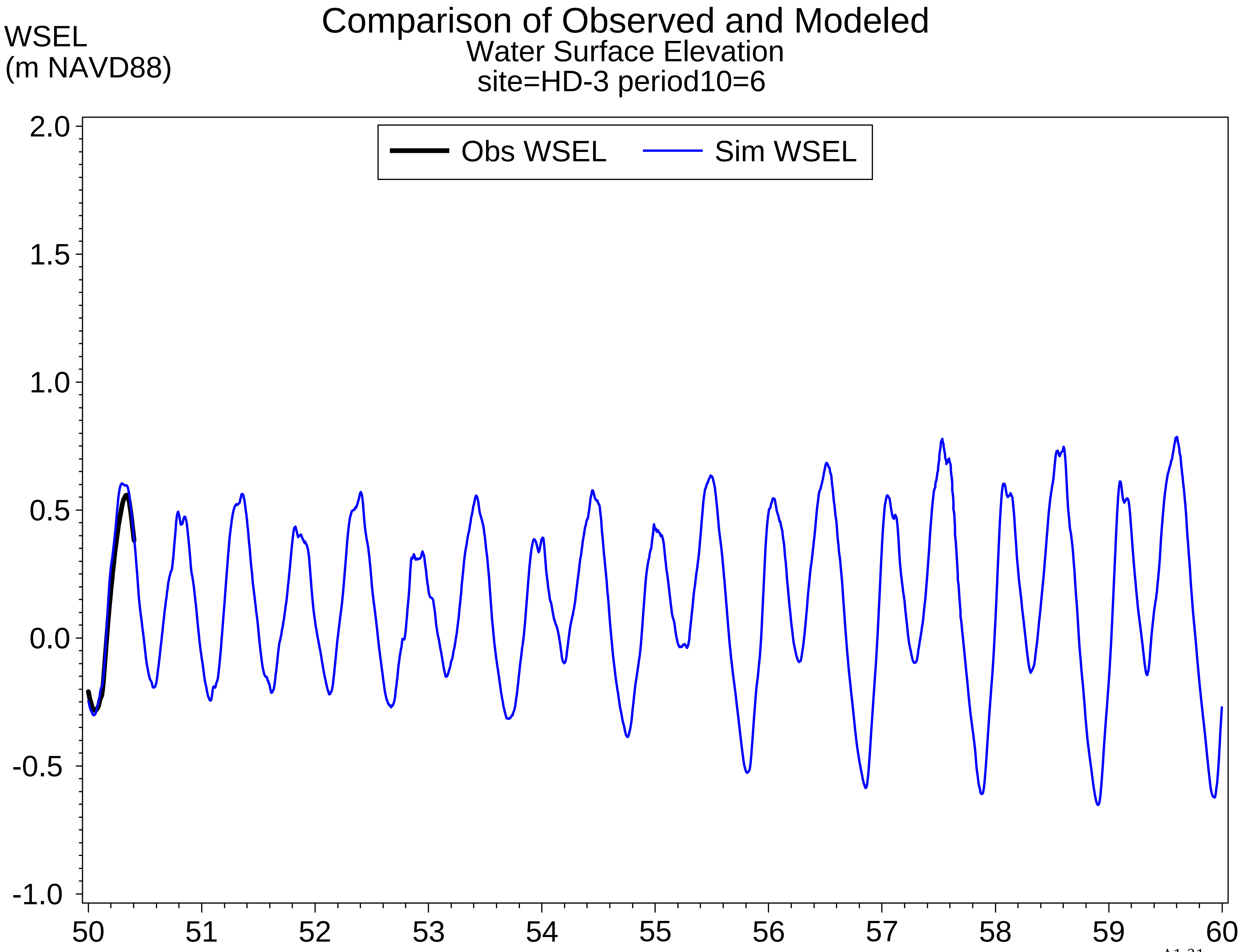
WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-3 period10=3
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
20
21
22
23
24
25
26
27
28
29
30

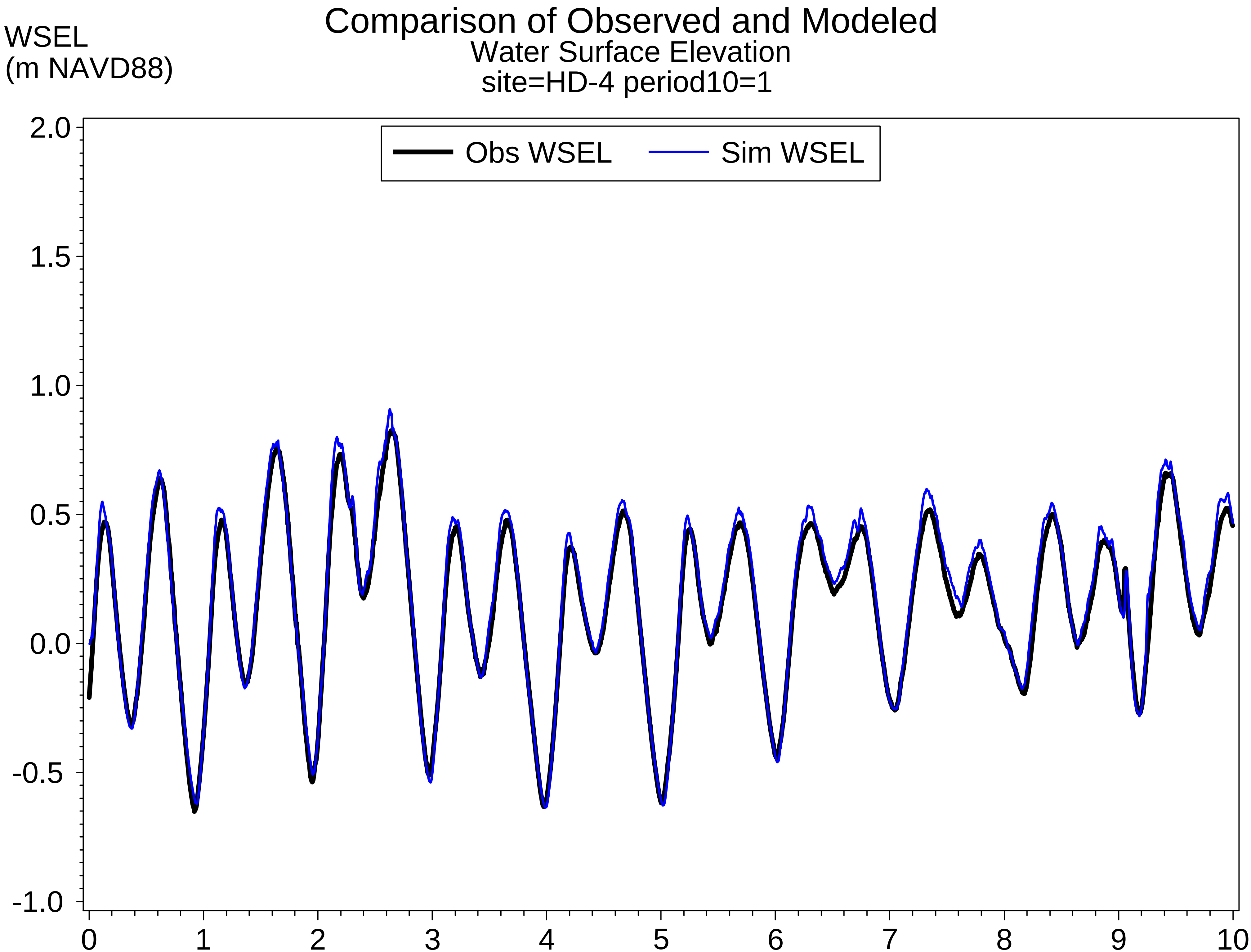


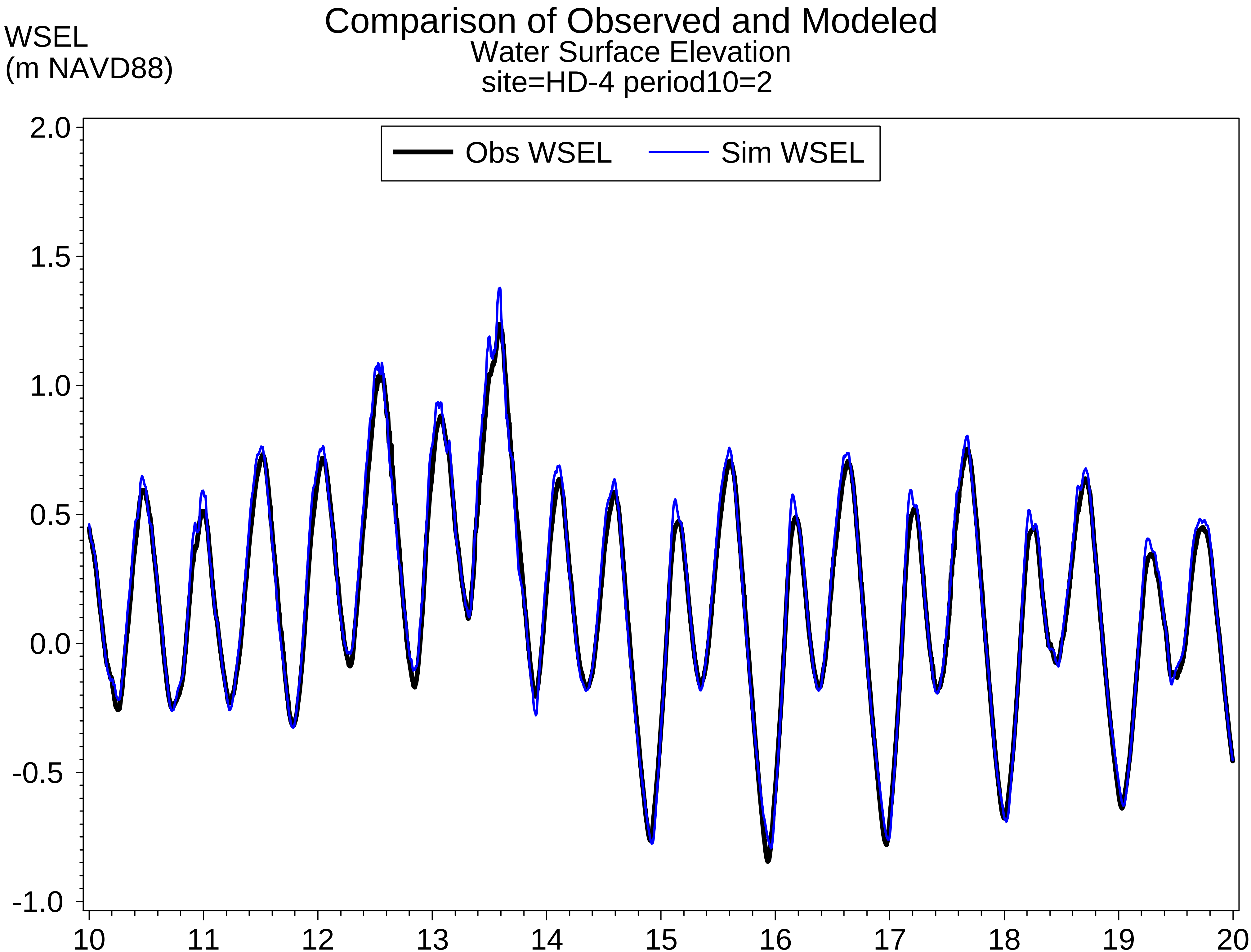
WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-3 period10=4
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
30
31
32
33
34
35
36
37
38
39
40

Comparison of Observed and Modeled
Water Surface Elevation
site=HD-3 period10=5

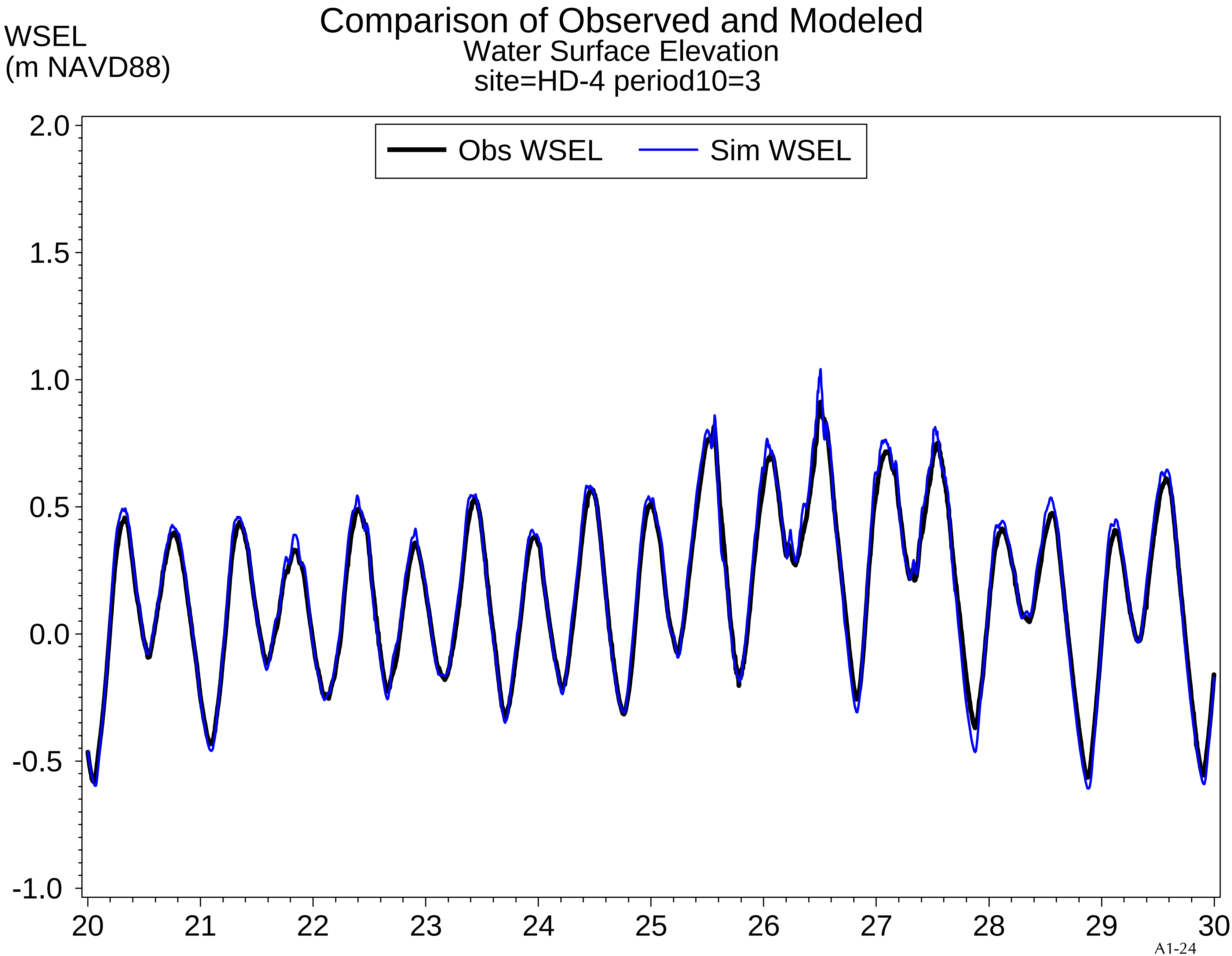



WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-3 period10=6
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
50
51
52
53
54
55
56
57
58
59
60

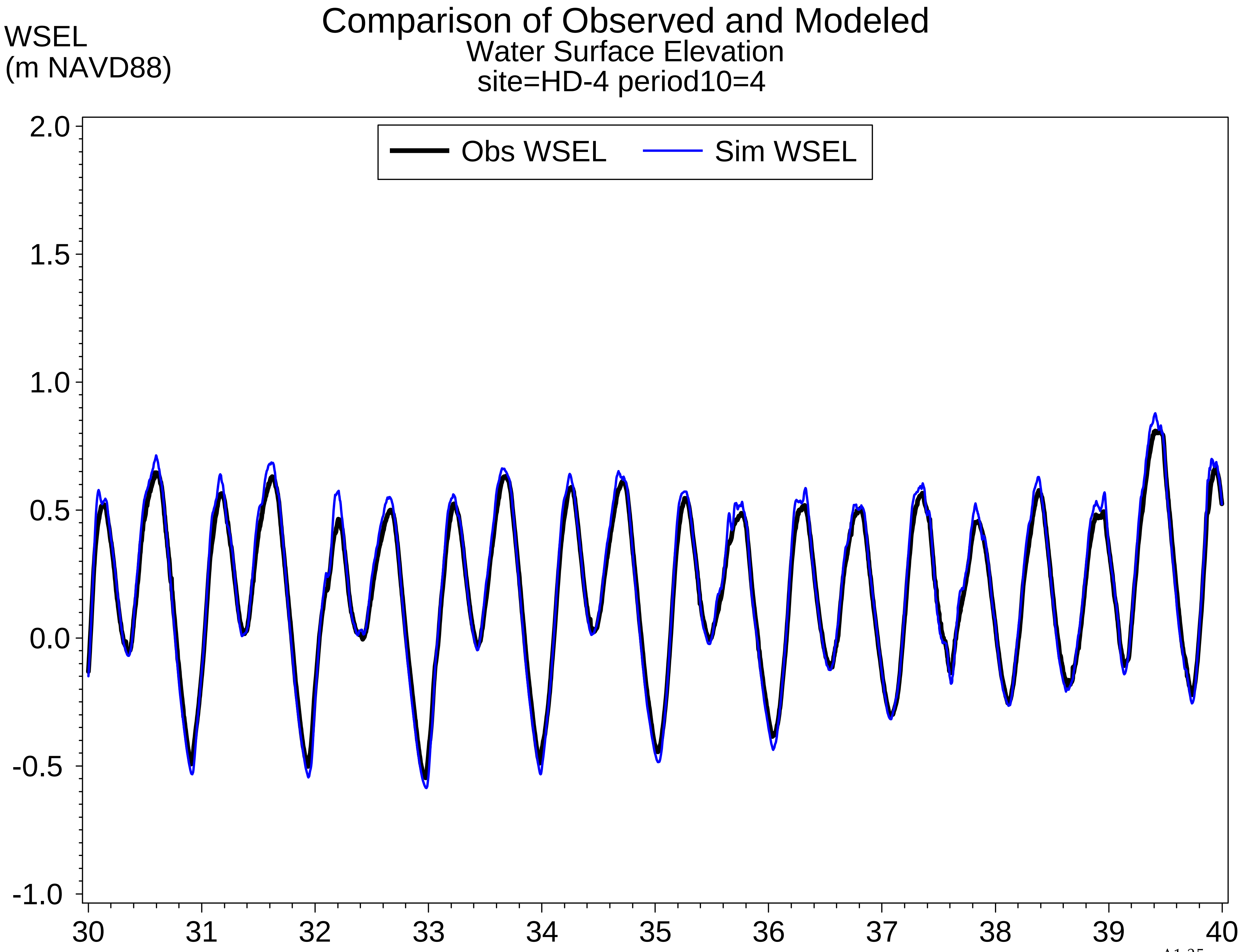

WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-4 period10=1
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
0
1
2
3
4
5
6
7
8
9
10

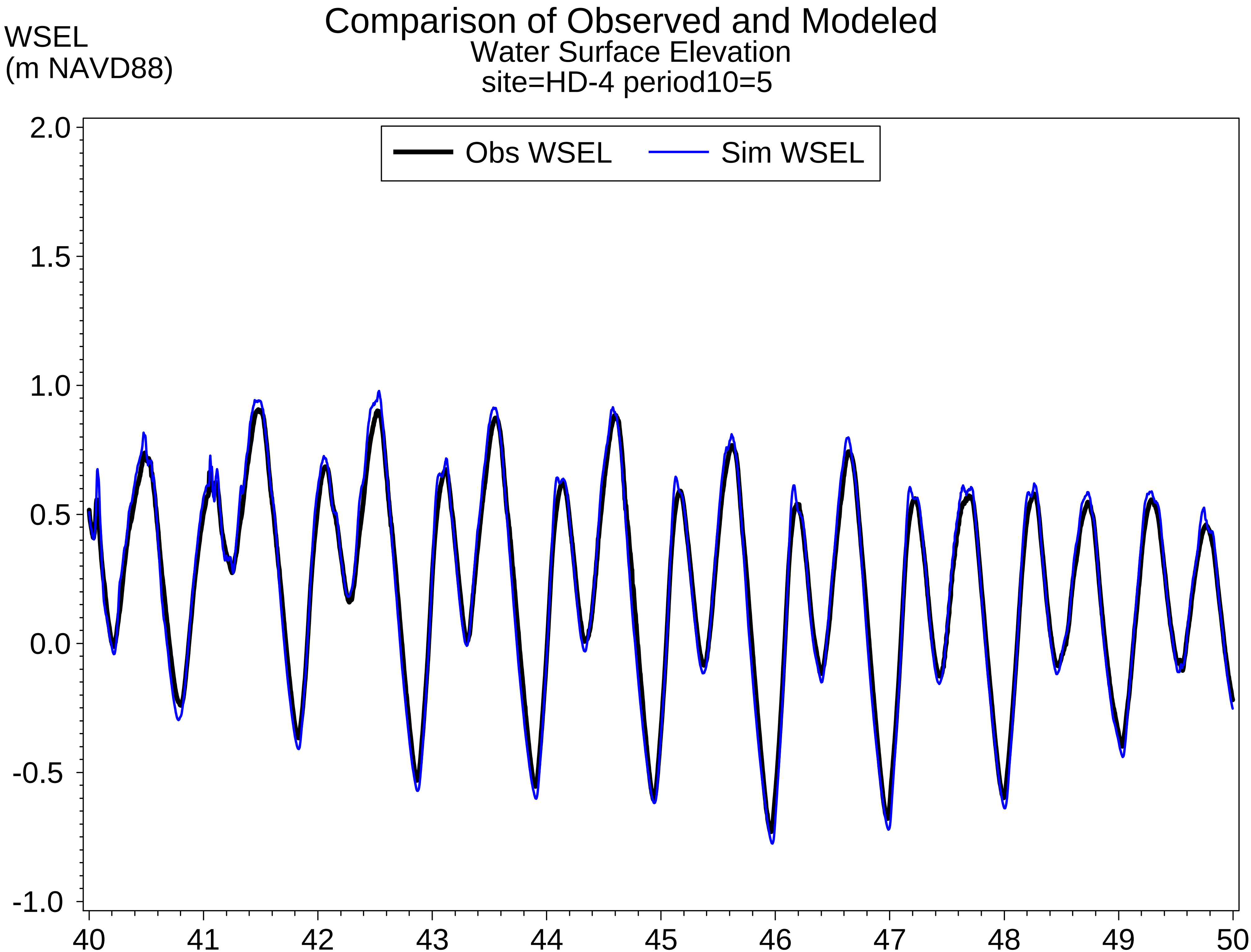


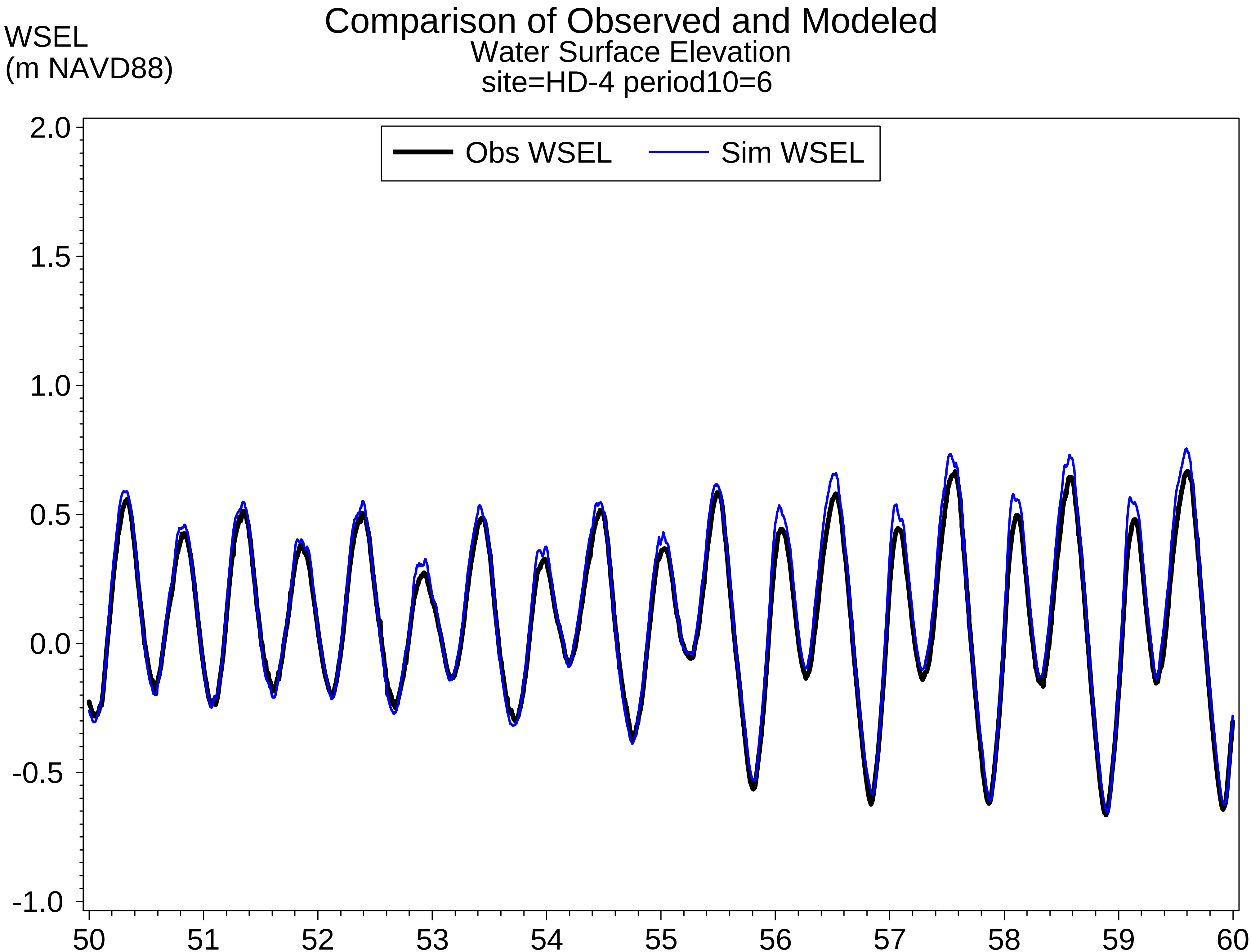
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-4 period10=2
WSEL
(m NAVD88)
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
10
11
12
13
14
15
16
17
18
19
20



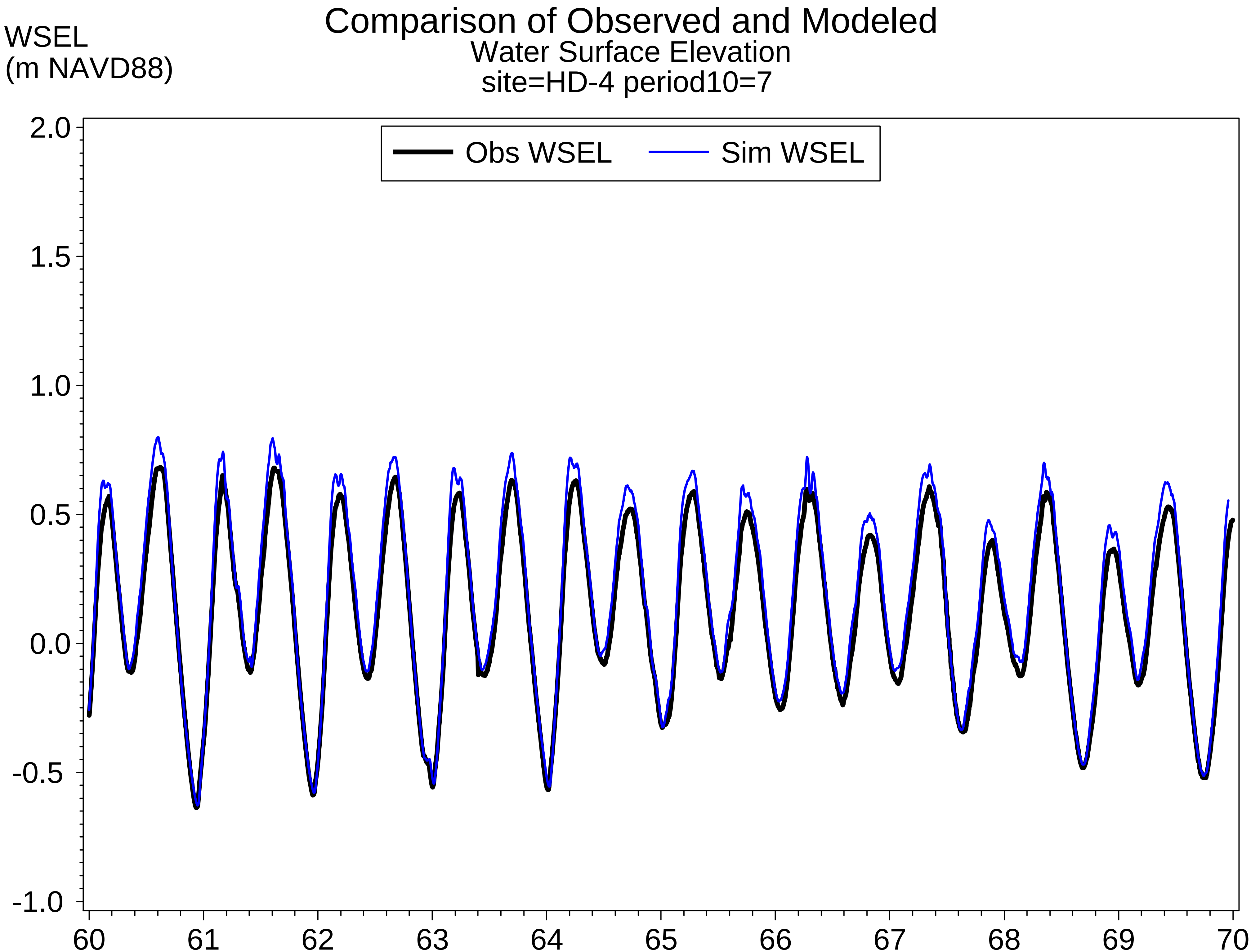
WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-4 period10=3
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
20
21
22
23
24
25
26
27
28
29
30


WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-4 period10=4
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
30
31
32
33
34
35
36
37
38
39
40

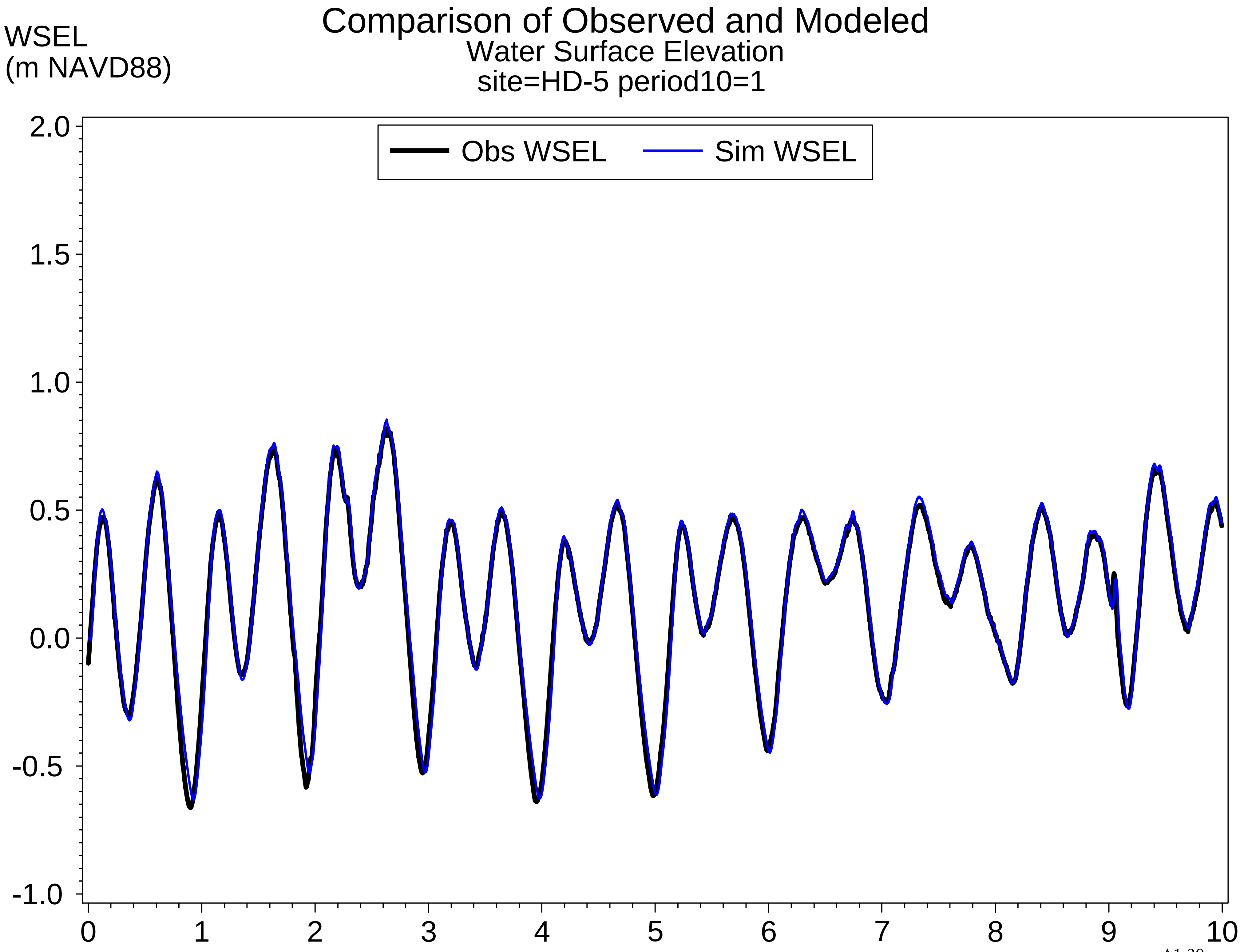

WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-4 period10=5
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
40
41
42
43
44
45
46
47
48
49
50



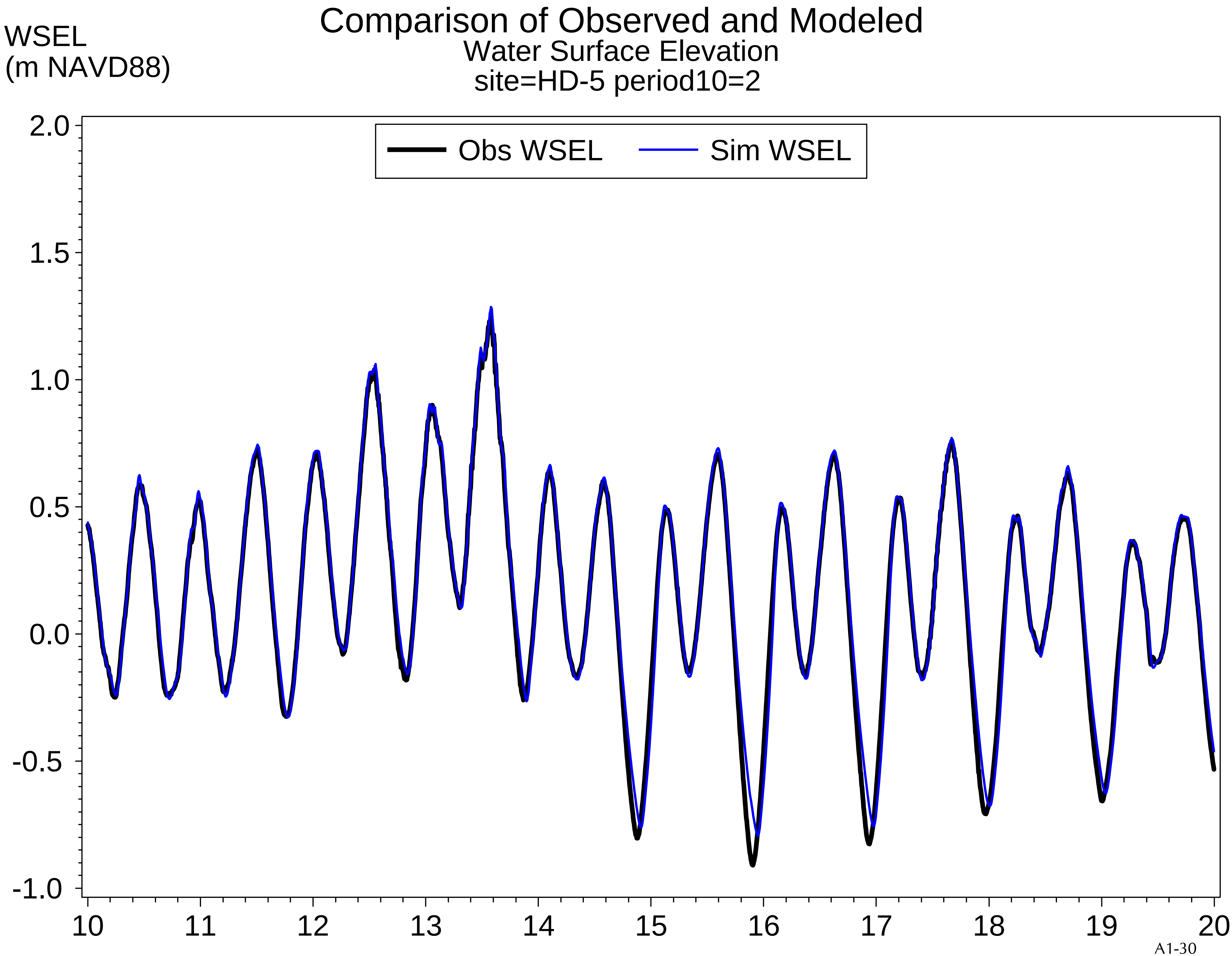
WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-4 period10=6
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
50
51
52
53
54
55
56
57
58
59
60



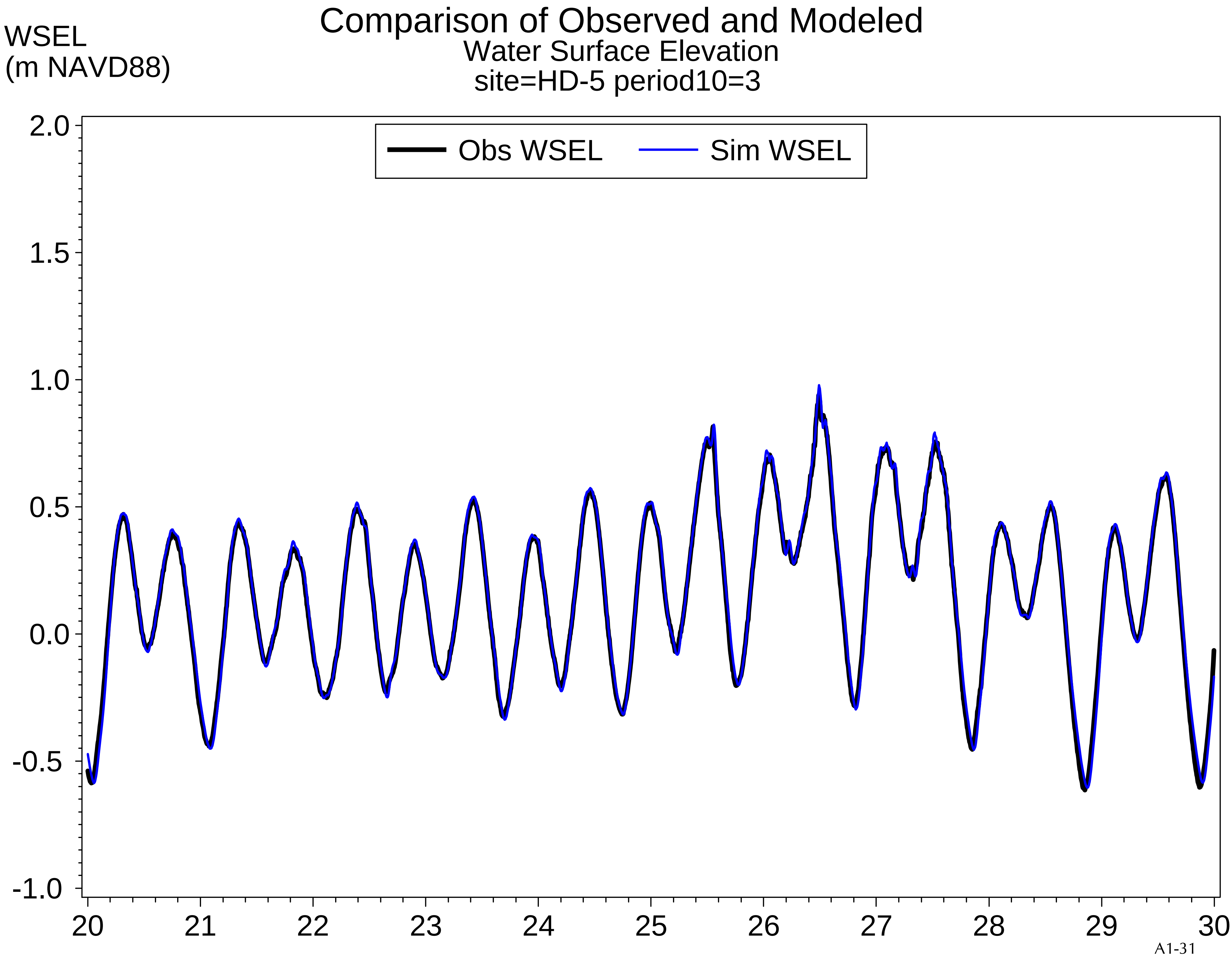
WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-4 period10=7
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
60
61
62
63
64
65
66
67
68
69
70

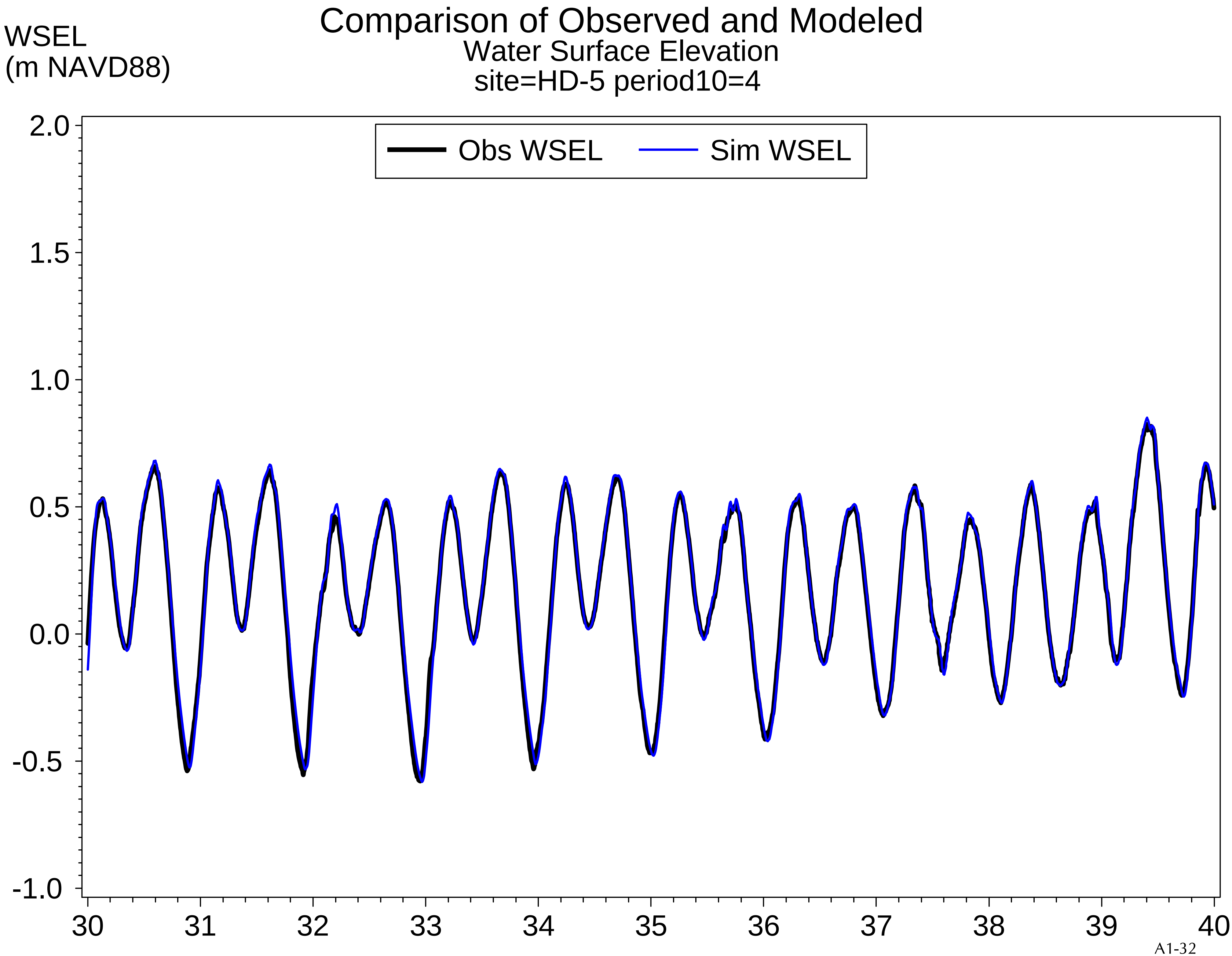


WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-5 period10=1
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
0
1
2
3
4
5
6
7
8
9
10

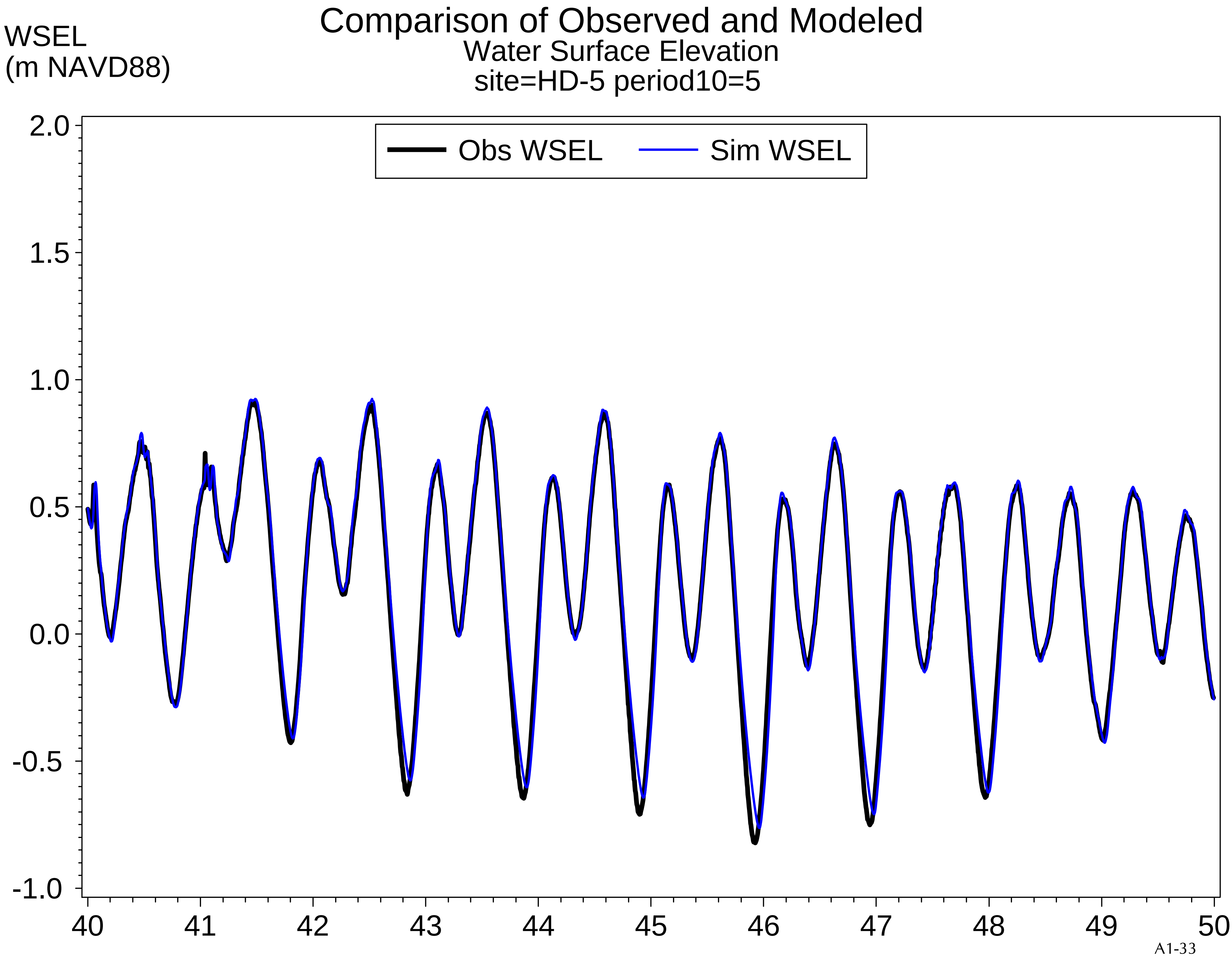


Comparison of Observed and Modeled
Water Surface Elevation
site=HD-5 period10=2
WSEL
(m NAVD88)
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
10
11
12
13
14
15
16
17
18
19
20

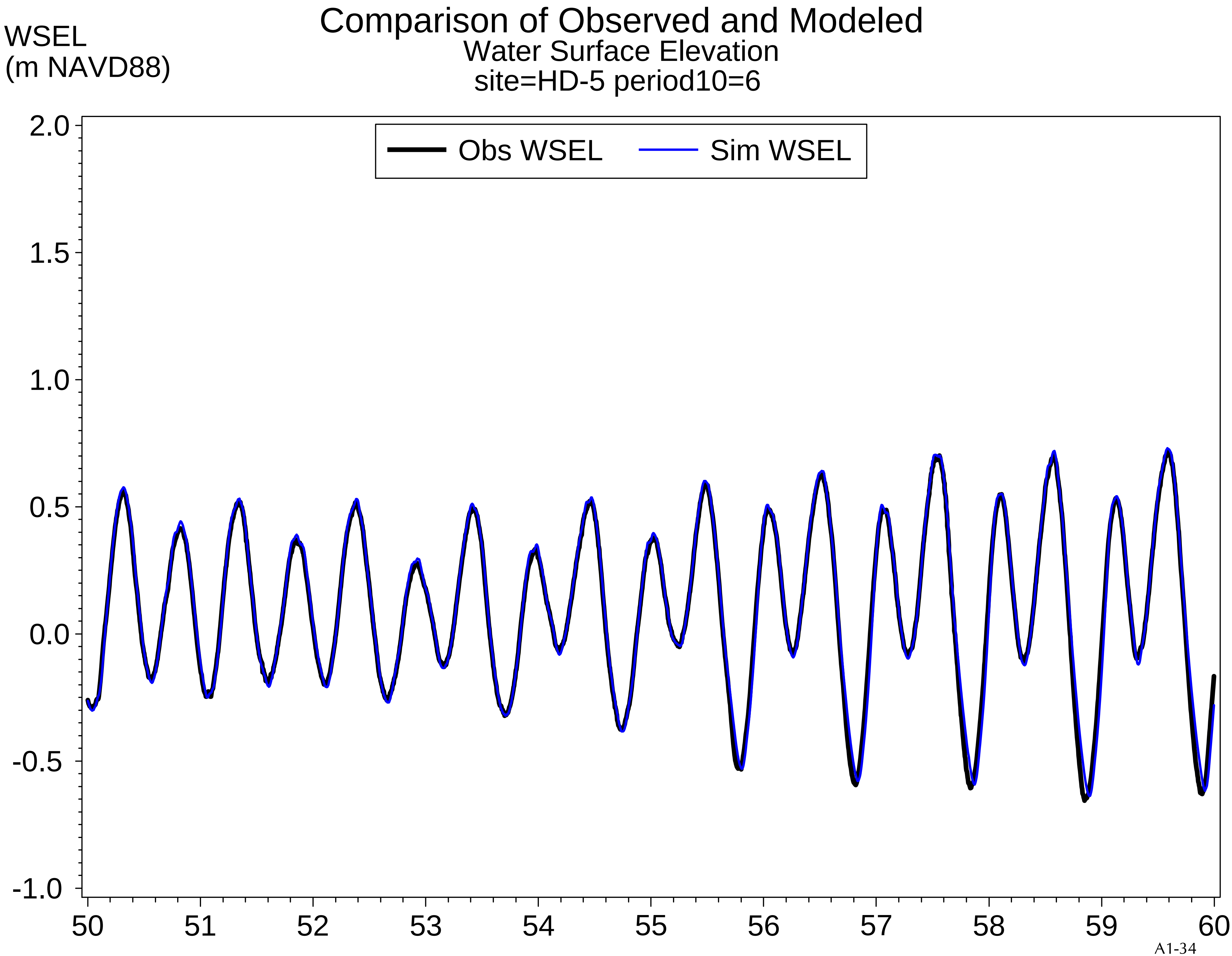

WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-5 period10=3
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
20
21
22
23
24
25
26
27
28
29
30



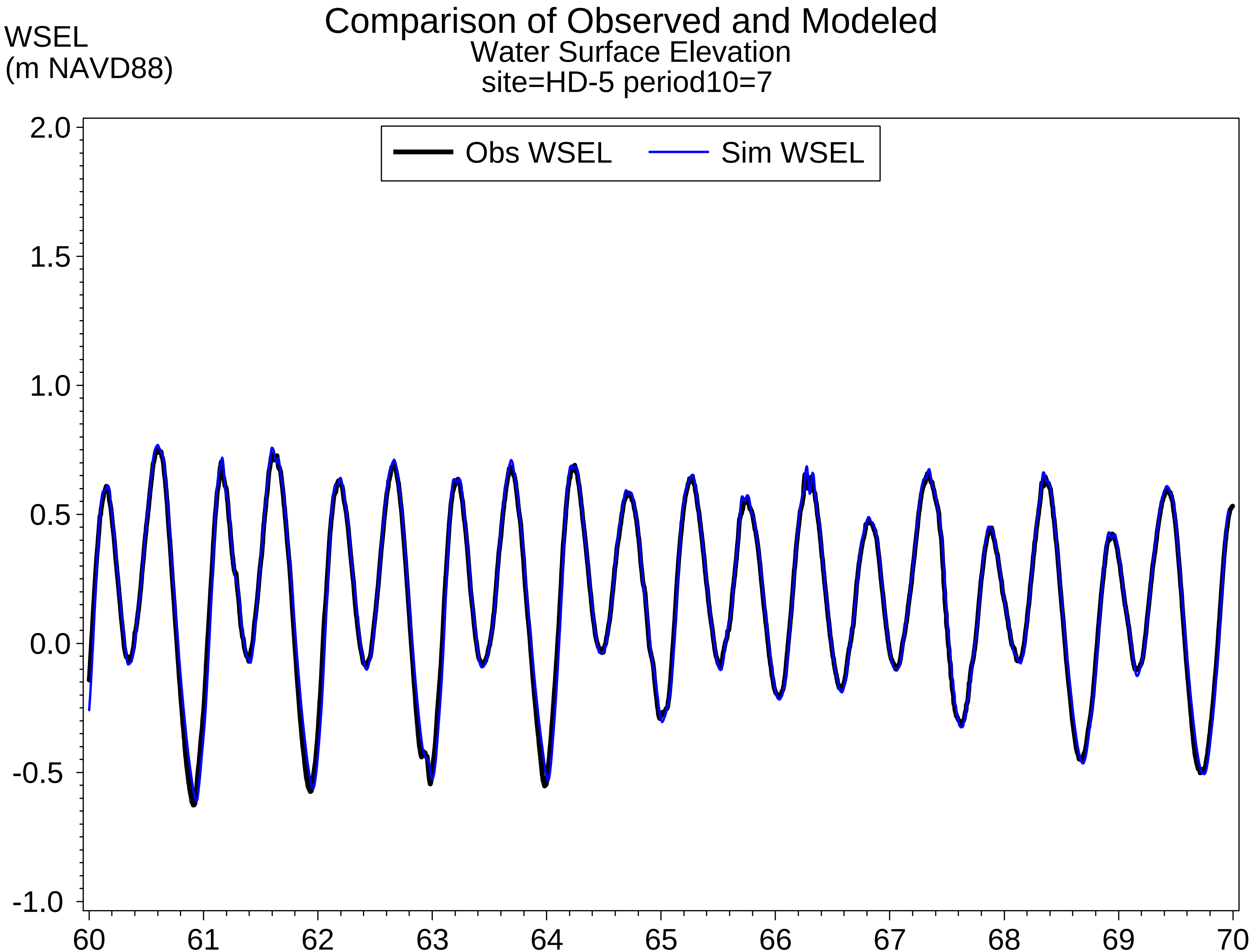
WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-5 period10=4
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
30
31
32
33
34
35
36
37
38
39
40

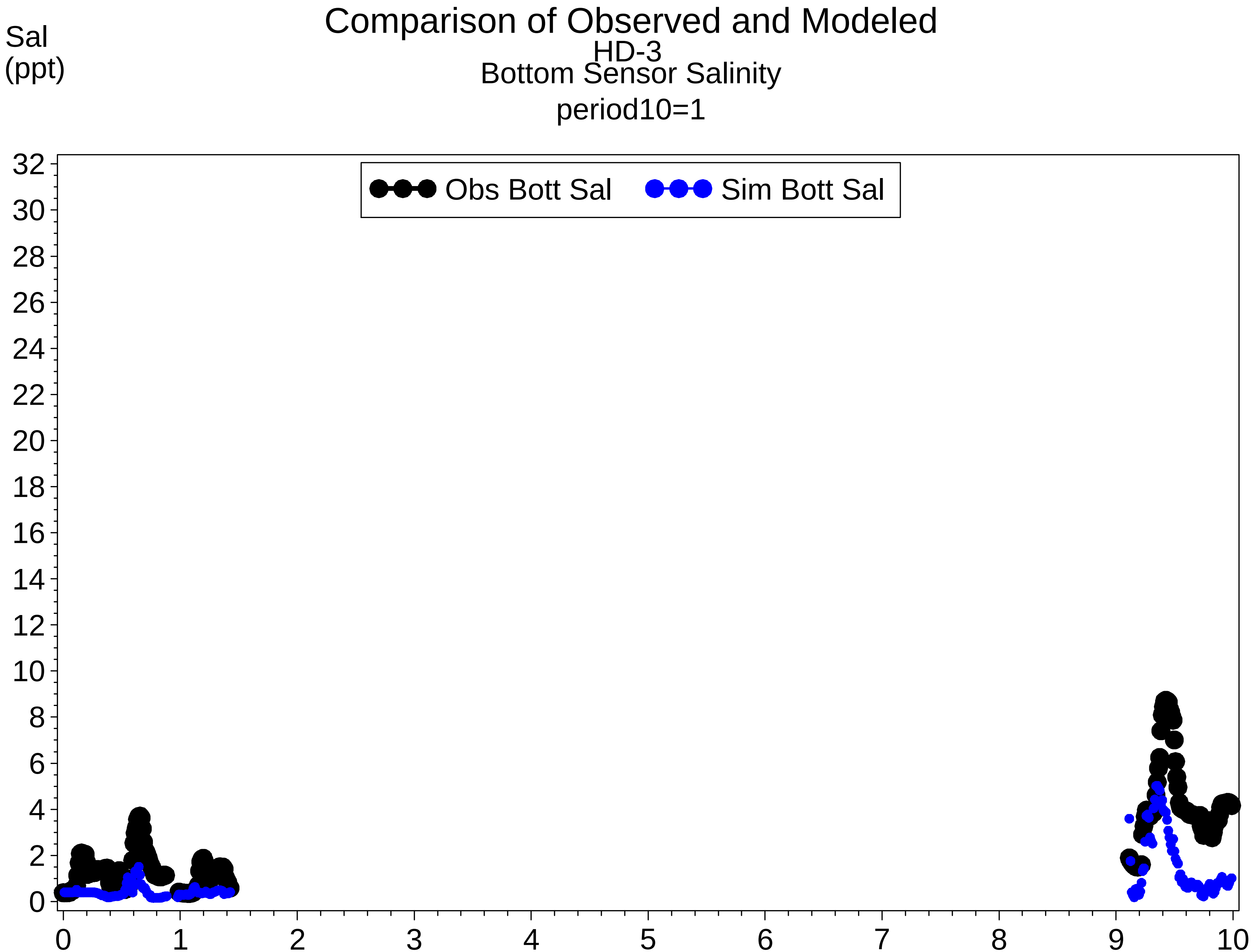


WSEL
(m NAVD88)
Comparison of Observed and Modeled
Water Surface Elevation
site=HD-5 period10=5
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
40
41
42
43
44
45
46
47
48
49
50

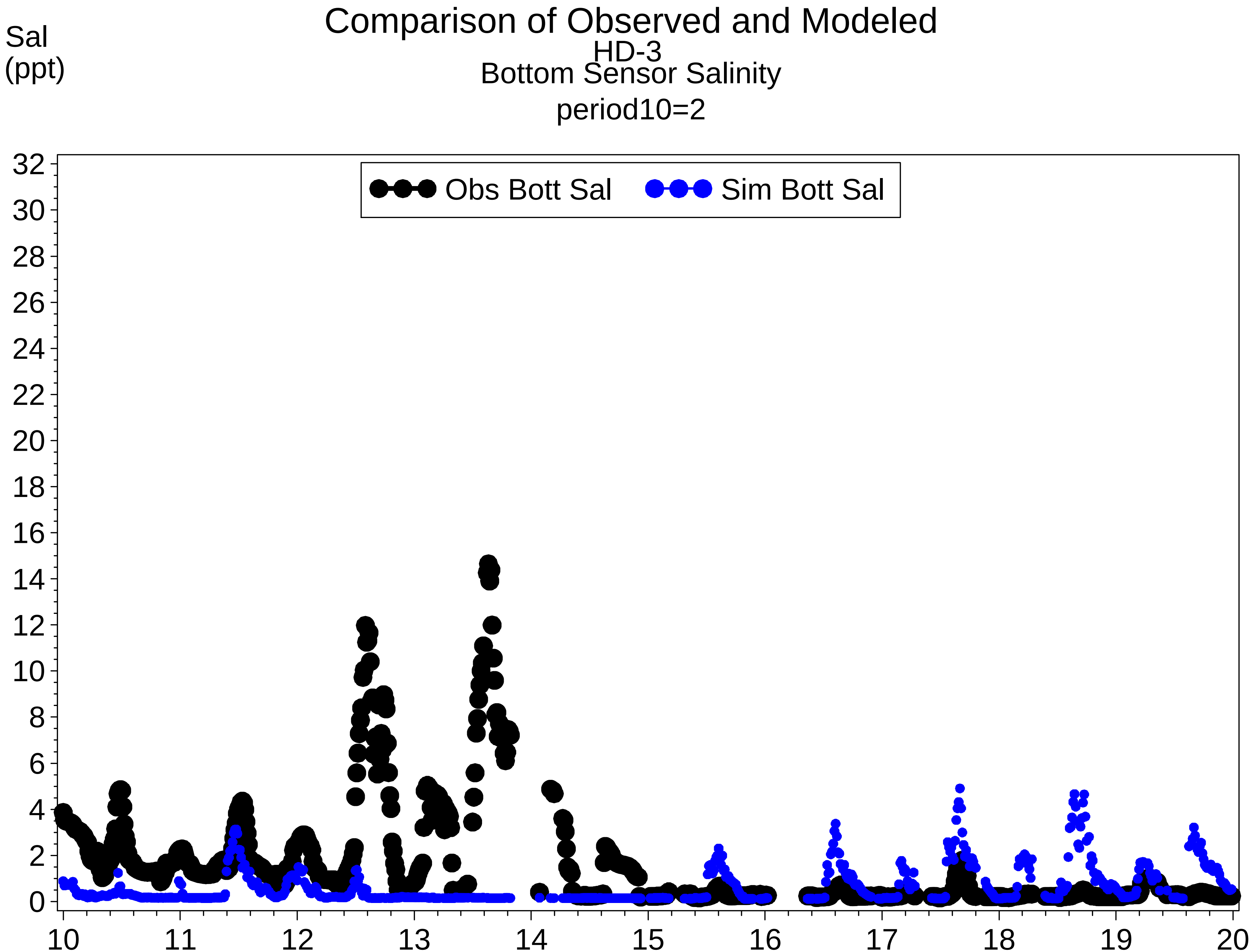


Comparison of Observed and Modeled
Water Surface Elevation
site=HD-5 period10=6
WSEL
(m NAVD88)
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
50
51
52
53
54
55
56
57
58
59
60

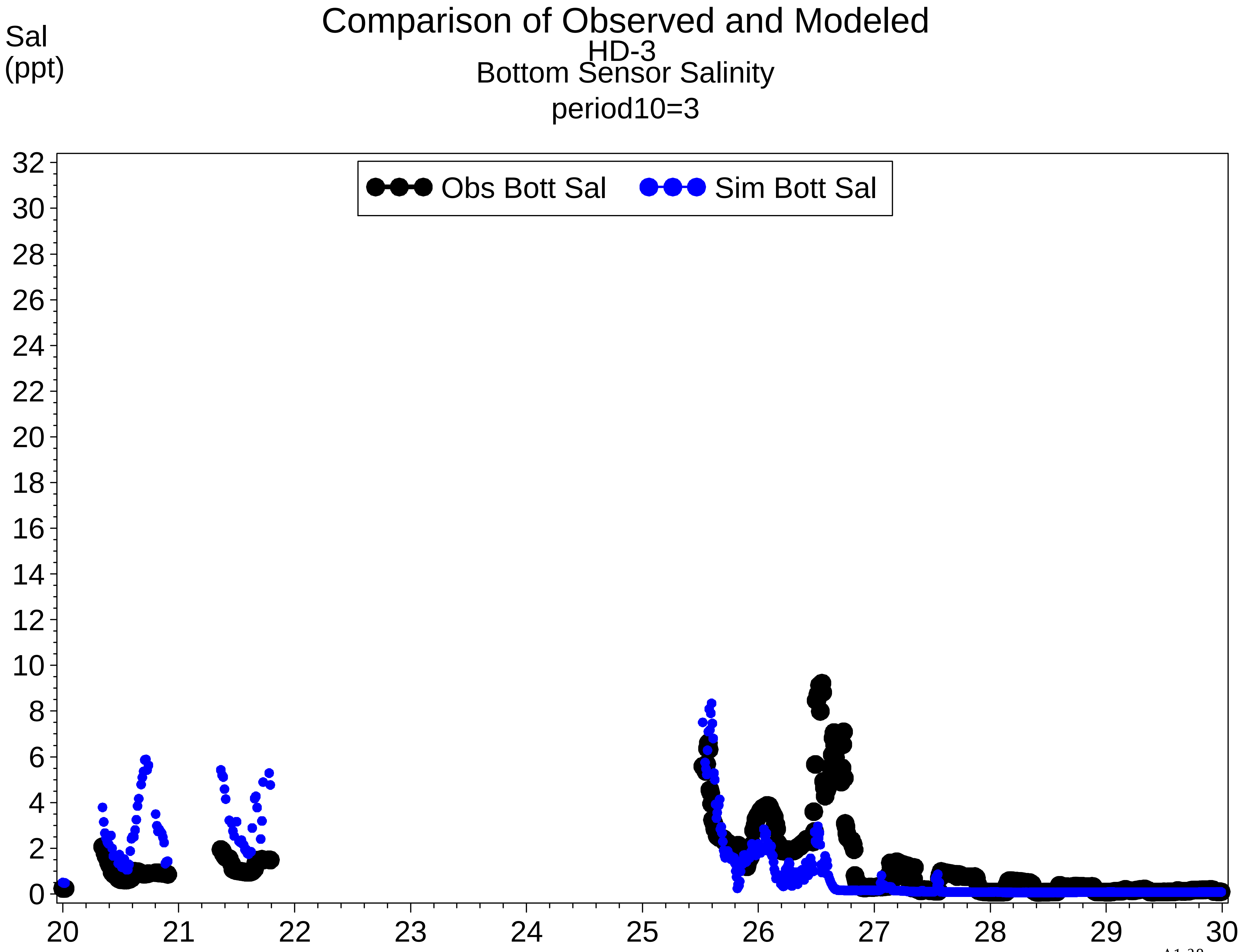

Comparison of Observed and Modeled
Water Surface Elevation
site=HD-5 period10=7
WSEL
(m NAVD88)
Obs WSEL
Sim WSEL
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
60
61
62
63
64
65
66
67
68
69
70

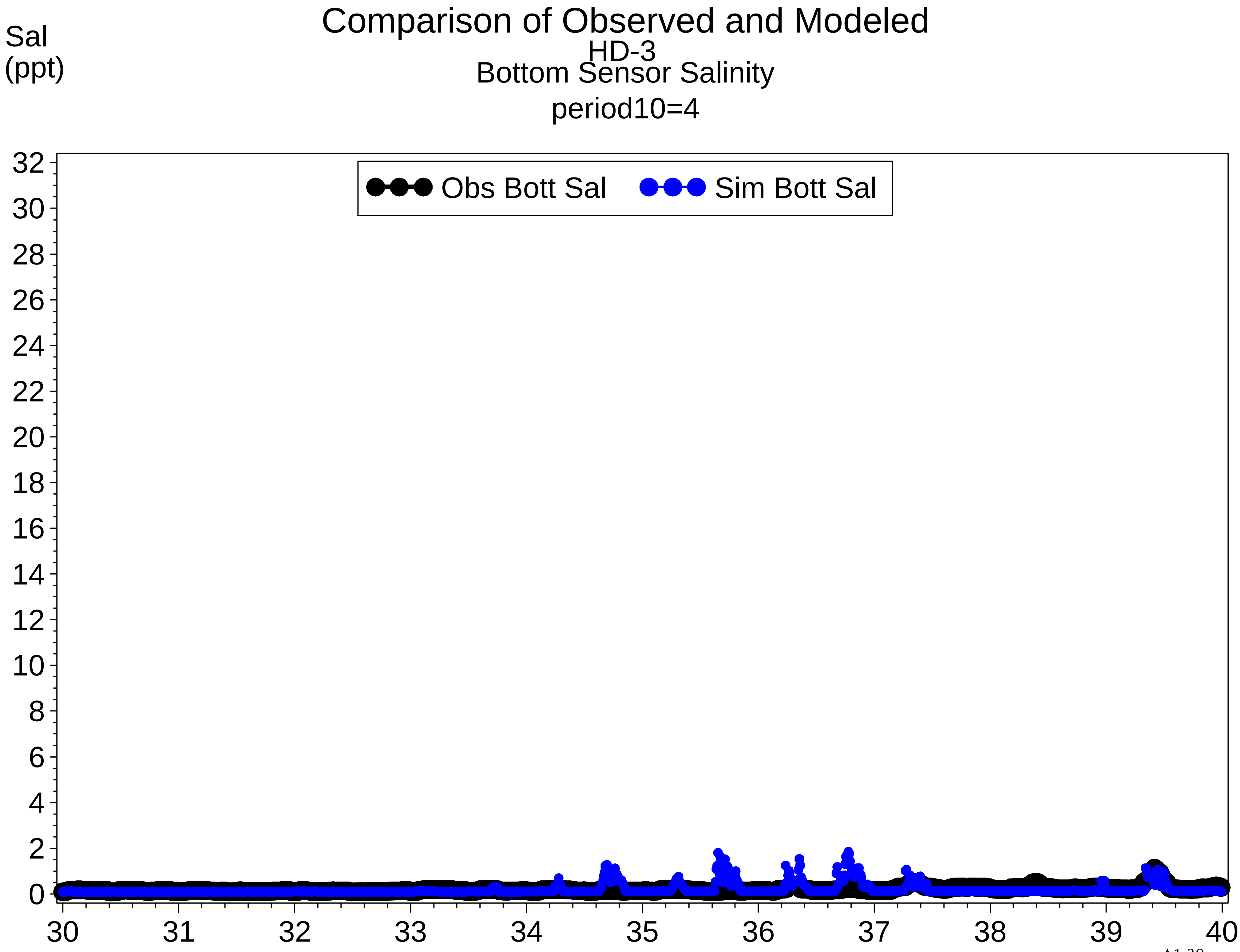


Sal
(ppt)
Comparison of Observed and Modeled
HD-3
Bottom Sensor Salinity
period10=1
Obs Bott Sal
Sim Bott Sal
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
0
1
2
3
4
5
6
7
8
9
10

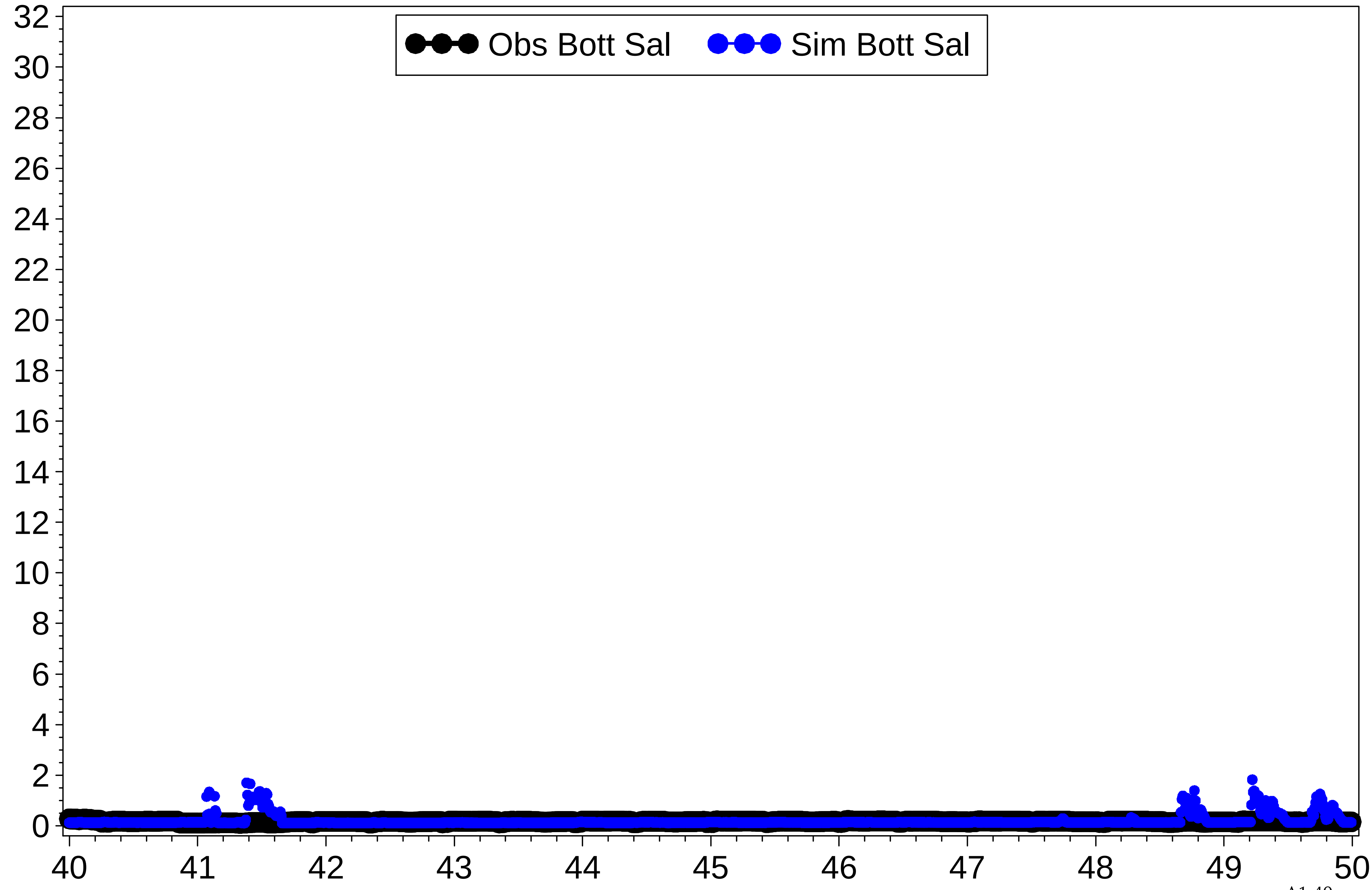


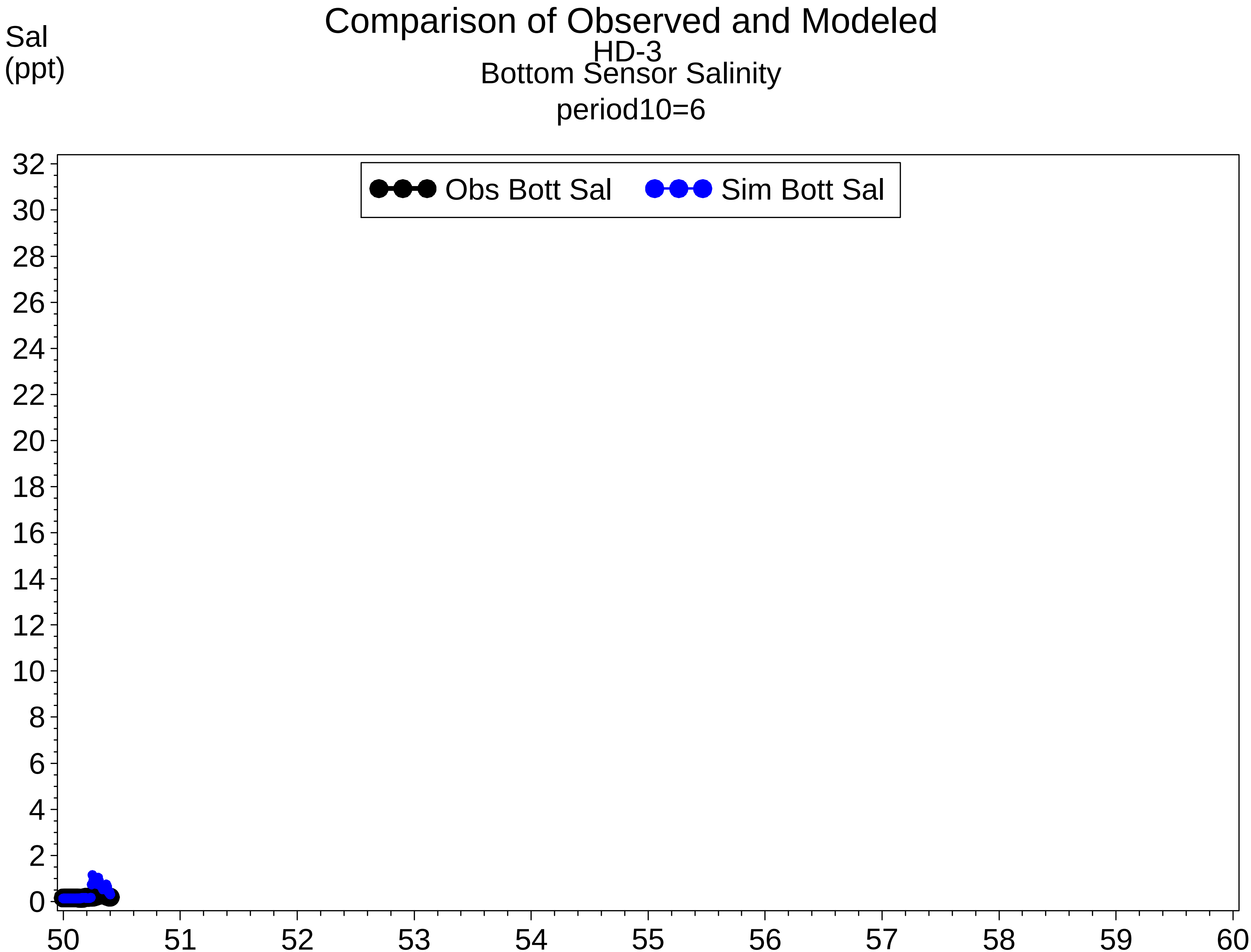
Comparison of Observed and Modeled
HD-3
Bottom Sensor Salinity
period10=2
Sal
(ppt)
Obs Bott Sal
Sim Bott Sal
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
10
11
12
13
14
15
16
17
18
19
20

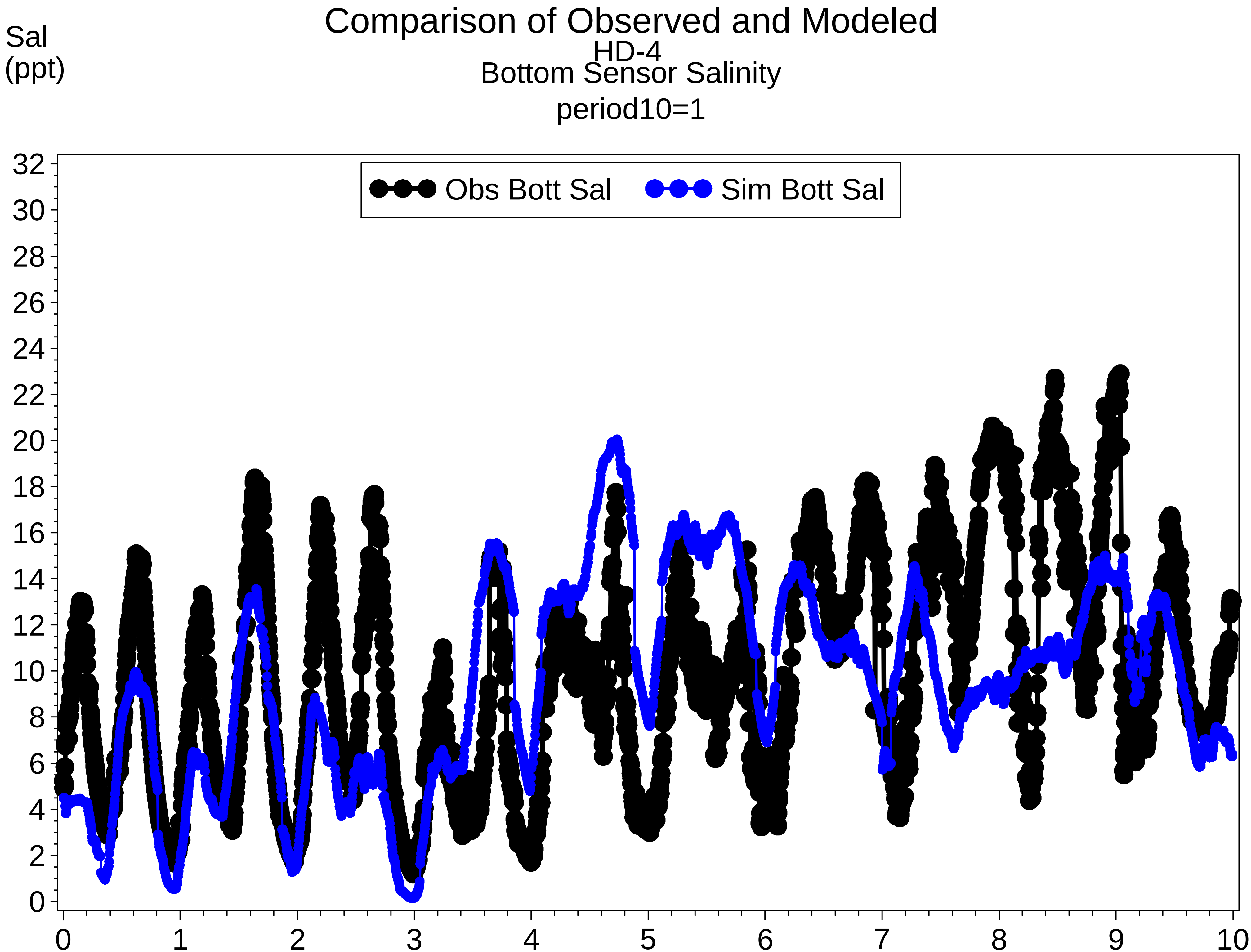

Comparison of Observed and Modeled
HD-3
Bottom Sensor Salinity
period10=3
Sal (ppt)
Obs Bott Sal
Sim Bott Sal
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
20
21
22
23
24
25
26
27
28
29
30


Comparison of Observed and Modeled
HD-3
Bottom Sensor Salinity
period10=4
Sal
(ppt)
Obs Bott Sal
Sim Bott Sal
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
30
31
32
33
34
35
36
37
38
39
40

Comparison of Observed and Modeled
HD-3
Bottom Sensor Salinity
period10=5

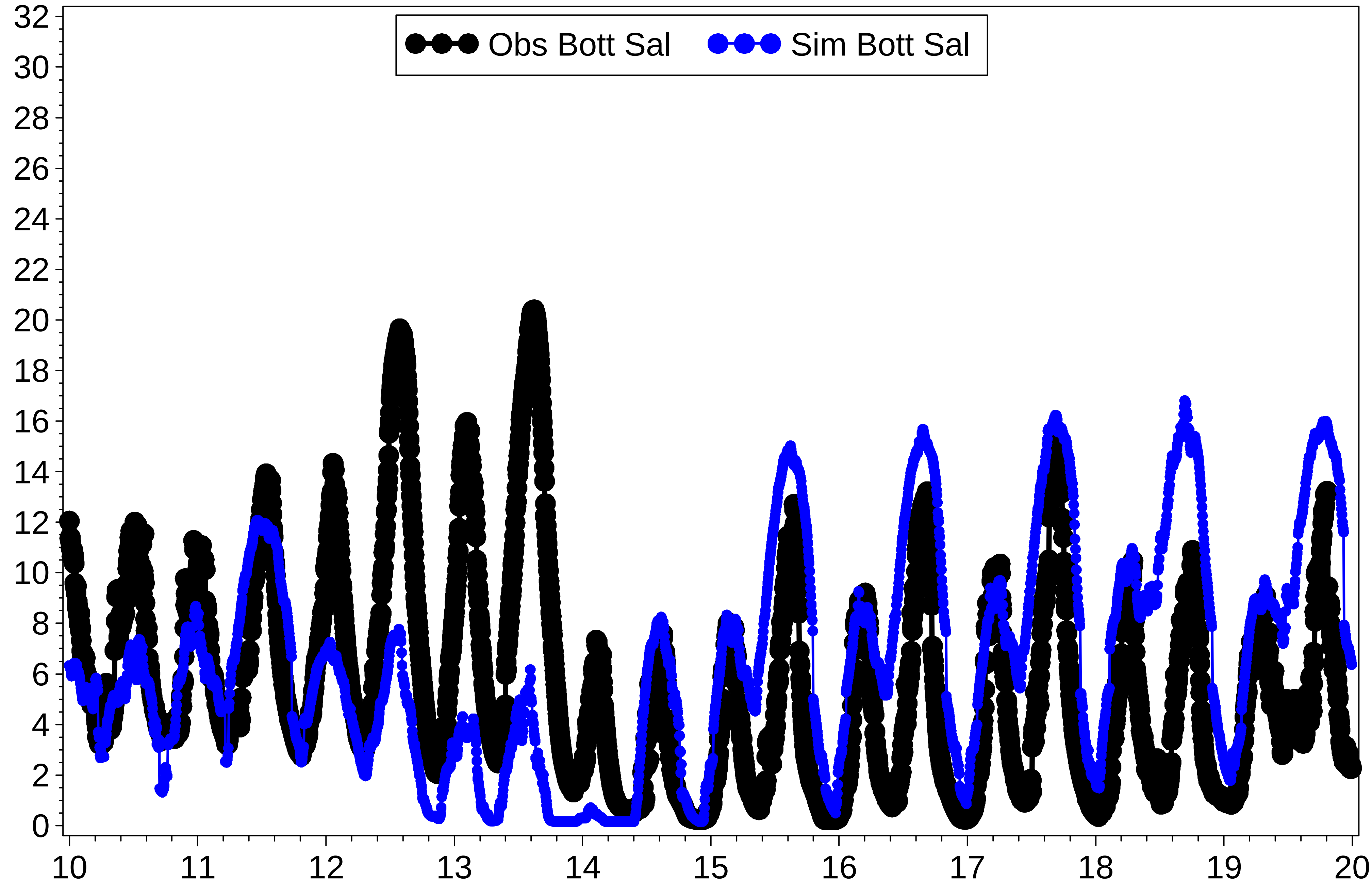


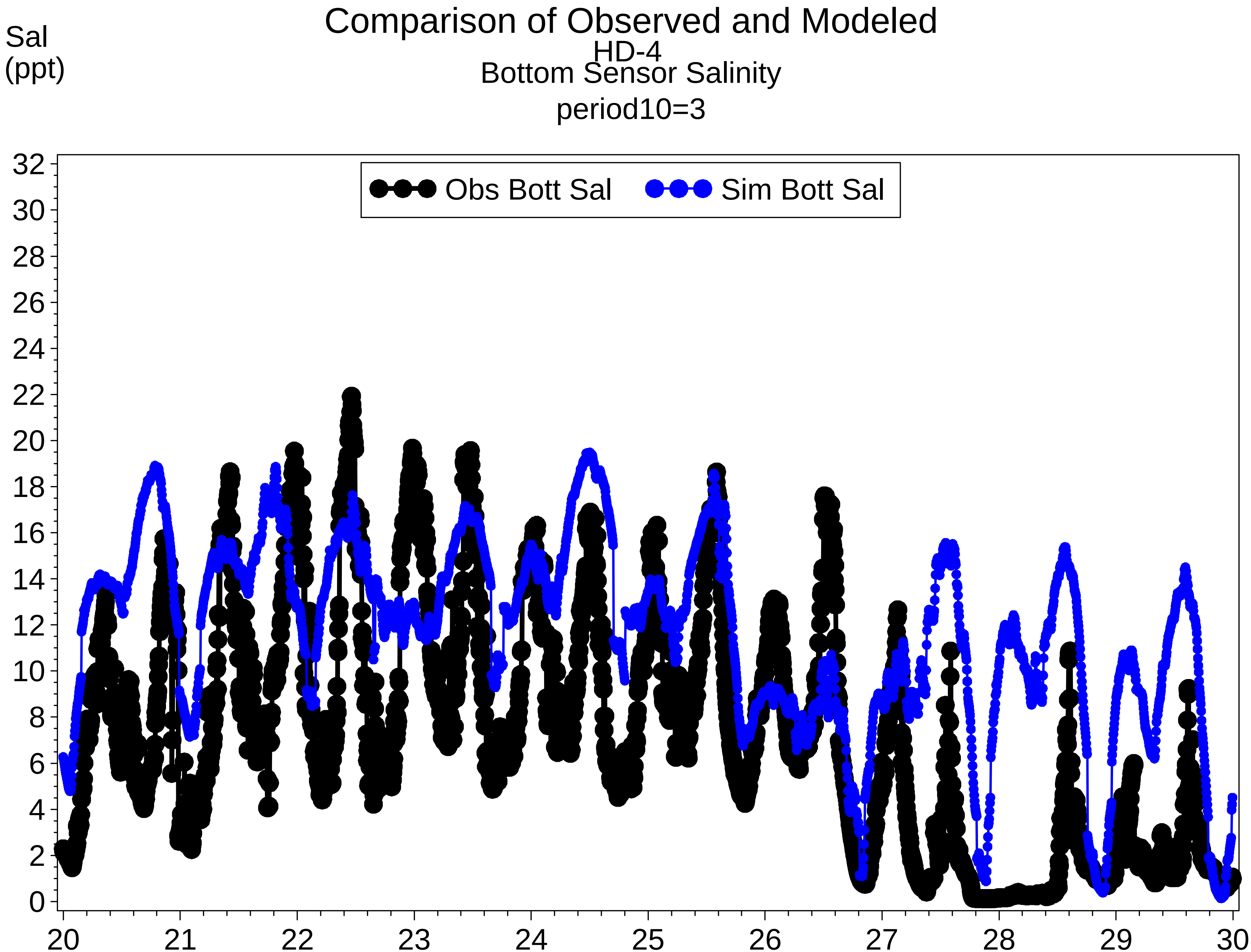

Comparison of Observed and Modeled
HD-3
Bottom Sensor Salinity
period10=6
Sal
(ppt)
Obs Bott Sal
Sim Bott Sal
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
50
51
52
53
54
55
56
57
58
59
60



Comparison of Observed and Modeled
HD-4
Bottom Sensor Salinity
period10=1
Sal
(ppt)
Obs Bott Sal
Sim Bott Sal
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
9
10

Comparison of Observed and Modeled
HD-4
Bottom Sensor Salinity
period10=2




Comparison of Observed and Modeled
HD-4
Bottom Sensor Salinity
period10=3
Sal
(ppt)
Obs Bott Sal
Sim Bott Sal
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
20
21
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23
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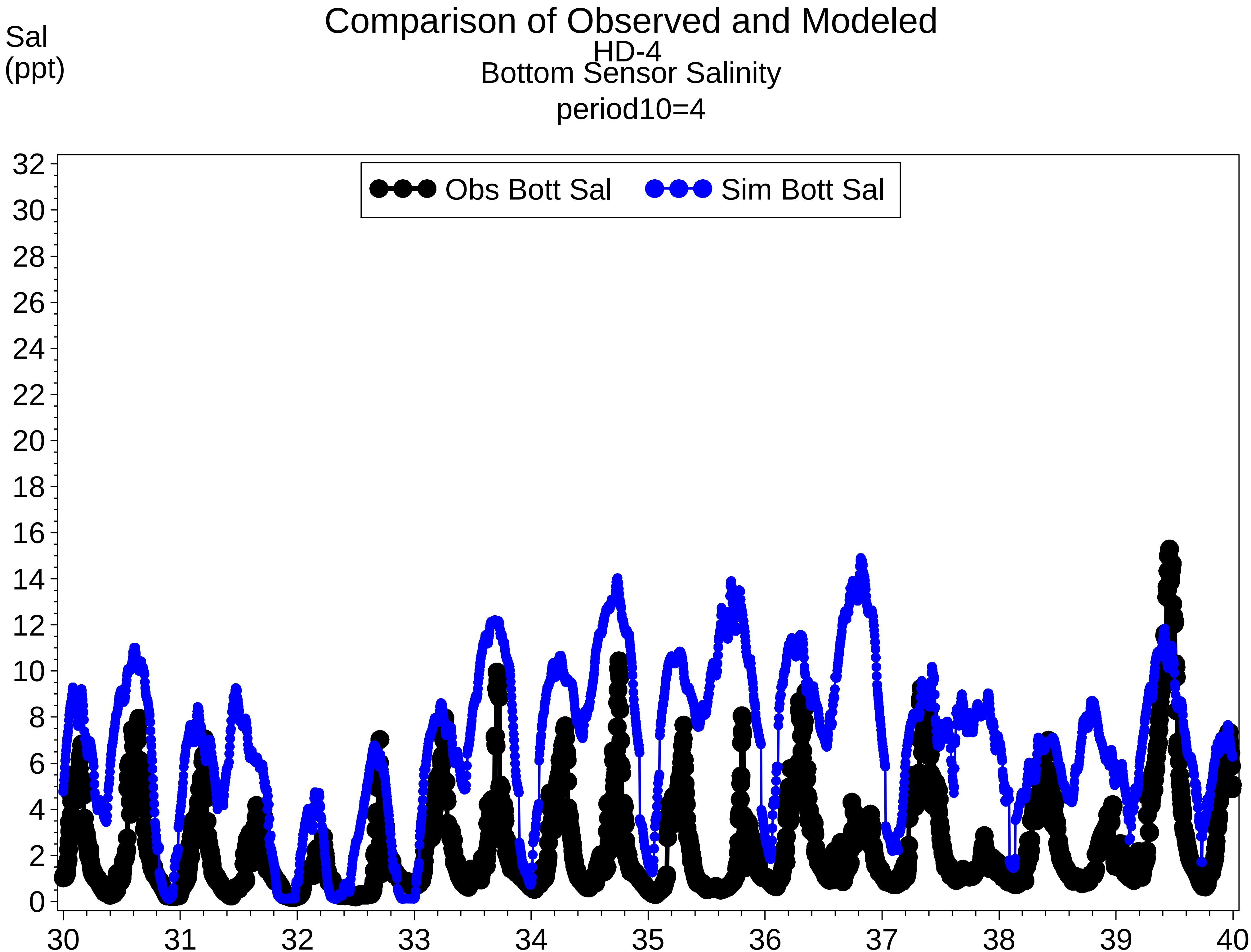
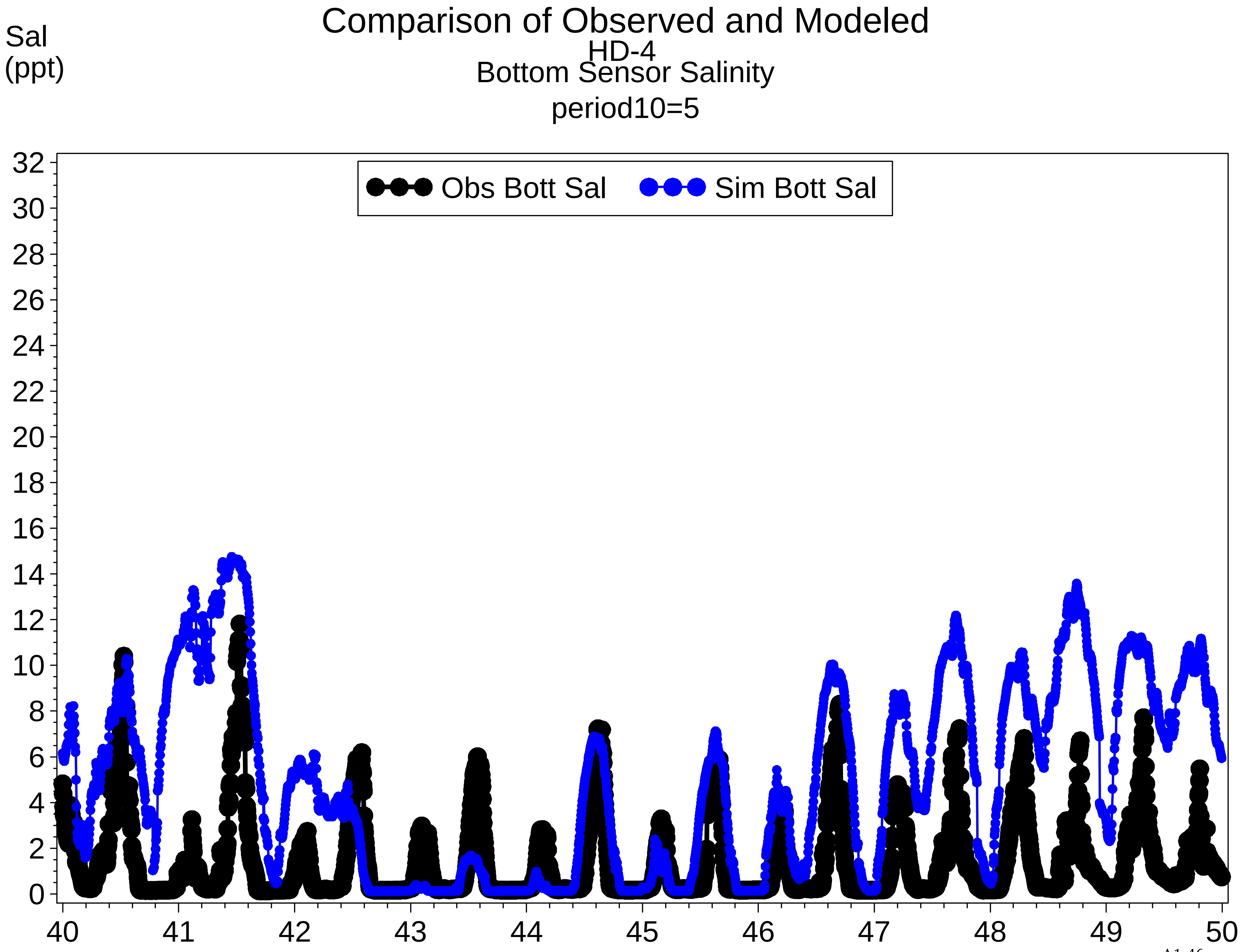
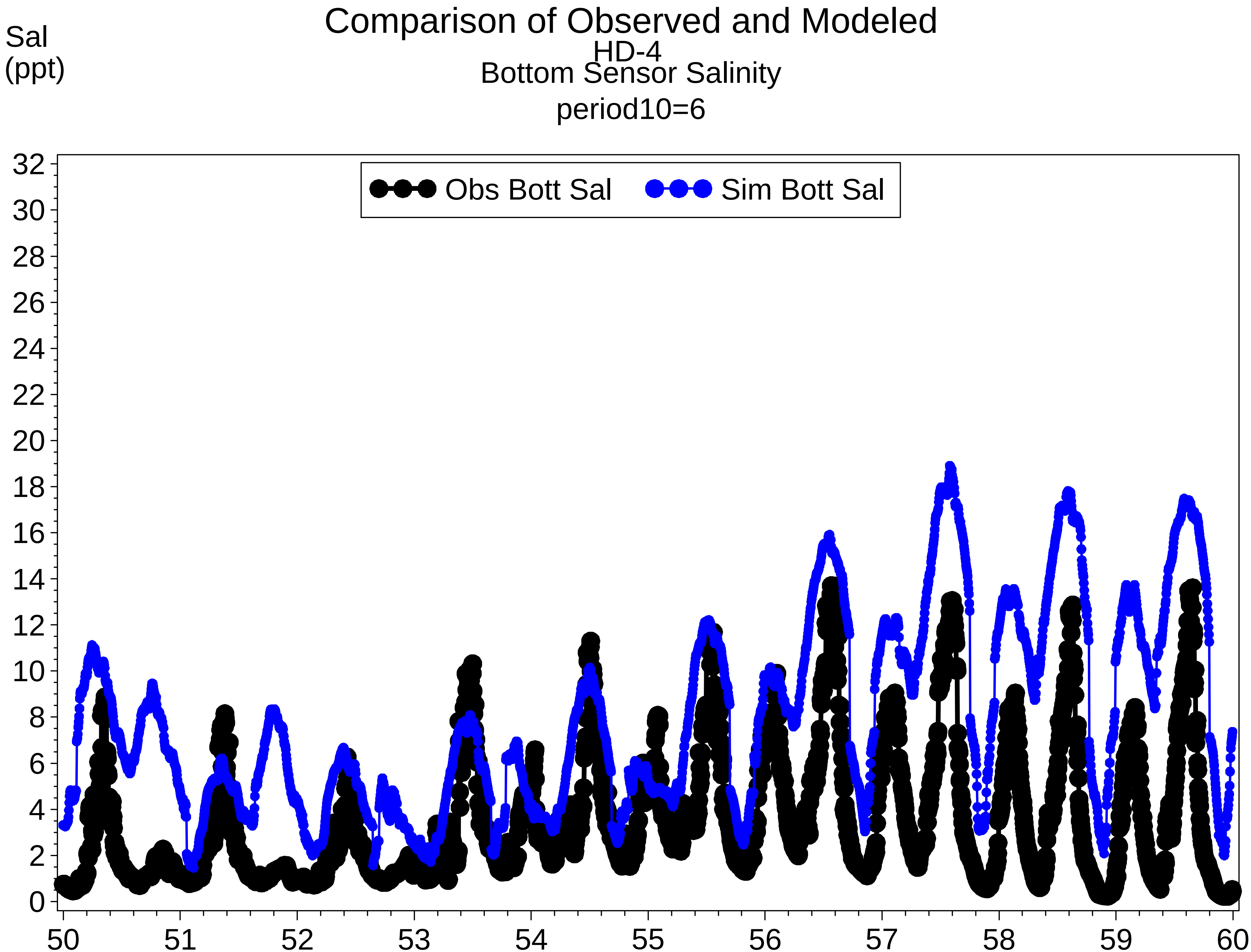
27
28
29
30

A1-44



Comparison of Observed and Modeled
HD-4
Bottom Sensor Salinity
period10=4
Sal
(ppt)
Obs Bott Sal
Sim Bott Sal
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
30
31
32
33
34
35
36
37
38
39
40


Comparison of Observed and Modeled
HD-4
Bottom Sensor Salinity
period10=5
Sal
(ppt)
Obs Bott Sal
Sim Bott Sal
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
40
41
42
43
44
45
46
47
48
49
50



Comparison of Observed and Modeled
HD-4
Bottom Sensor Salinity
period10=6
Sal
(ppt)
Obs Bott Sal
Sim Bott Sal
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
50
51
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53
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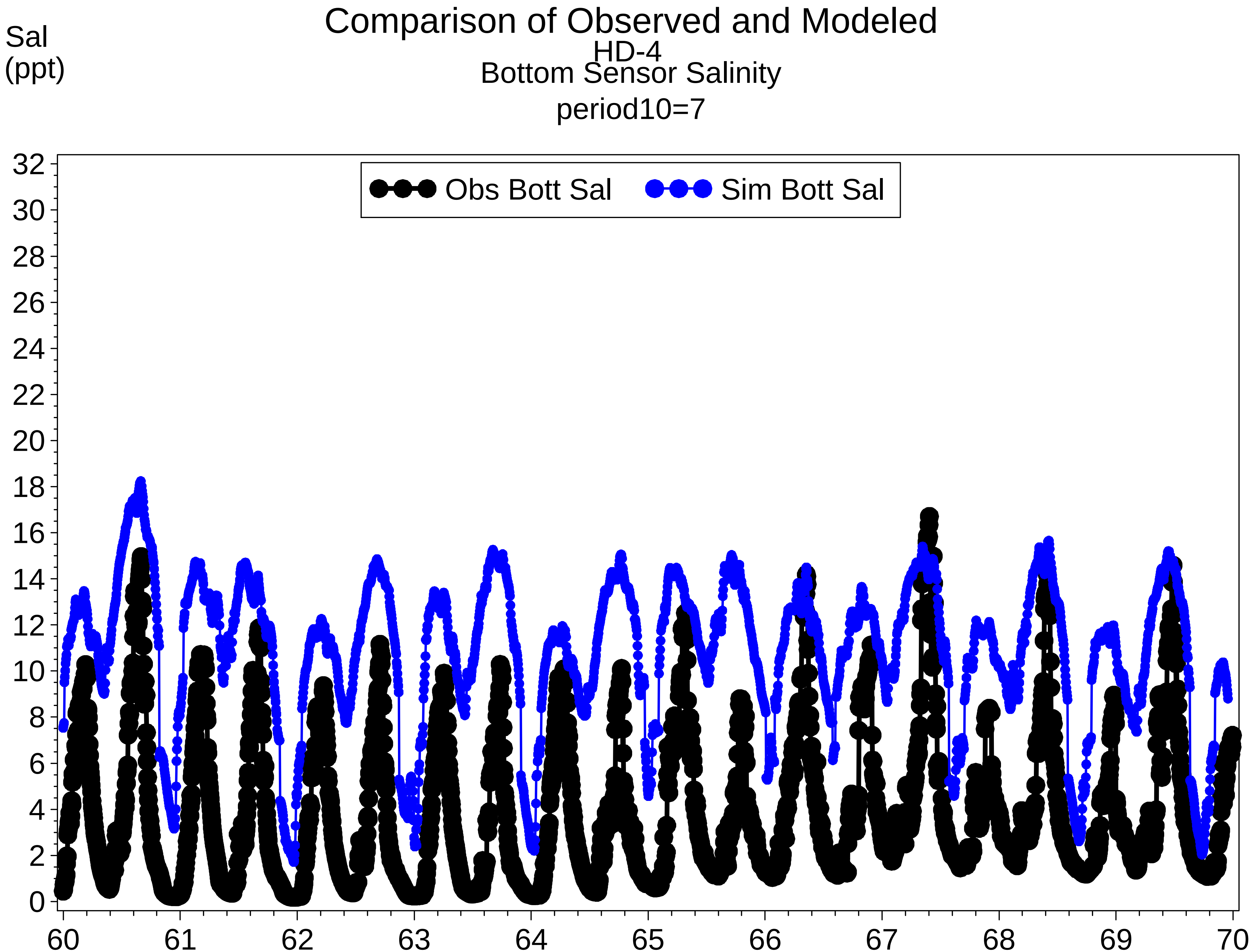

Comparison of Observed and Modeled
HD-4
Bottom Sensor Salinity
period10=7
Sal (ppt)
Obs Bott Sal
Sim Bott Sal
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
60
61
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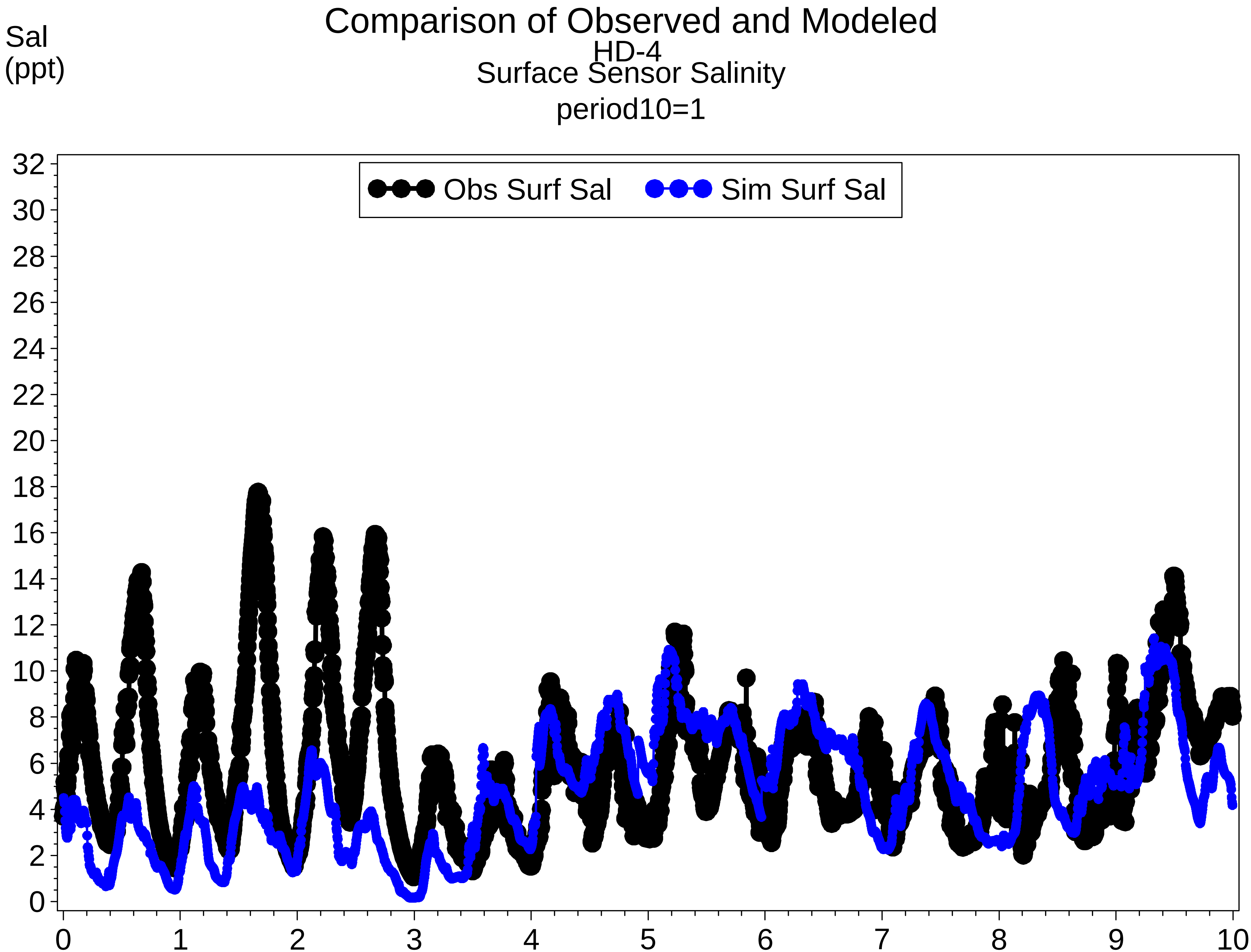
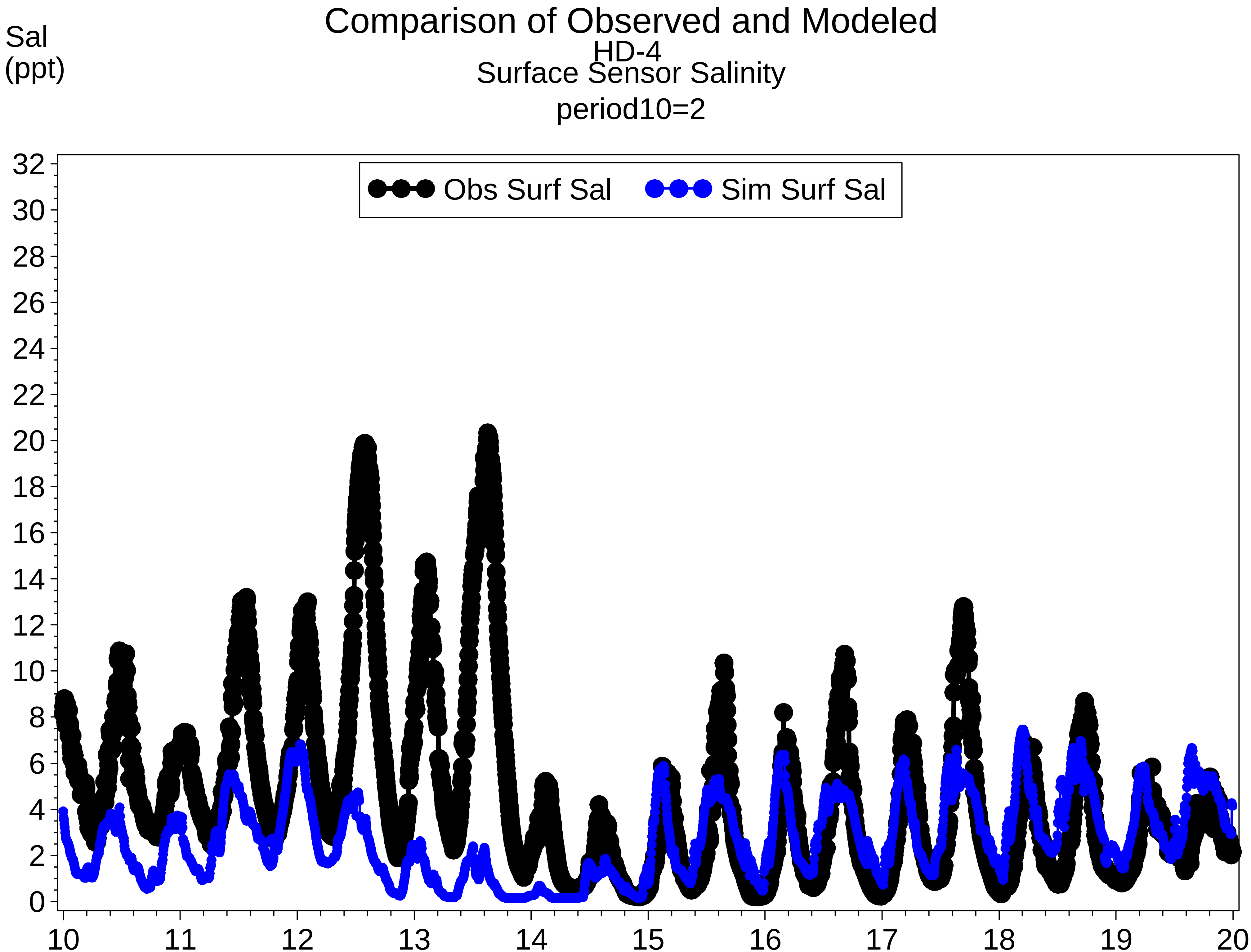


Comparison of Observed and Modeled
HD-4
Surface Sensor Salinity
period10=1
Sal
(ppt)
Obs Surf Sal
Sim Surf Sal
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
9
10


Comparison of Observed and Modeled
HD-4
Surface Sensor Salinity
period10=2
Sal
(ppt)
Obs Surf Sal
Sim Surf Sal
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
10
11
12
13
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17
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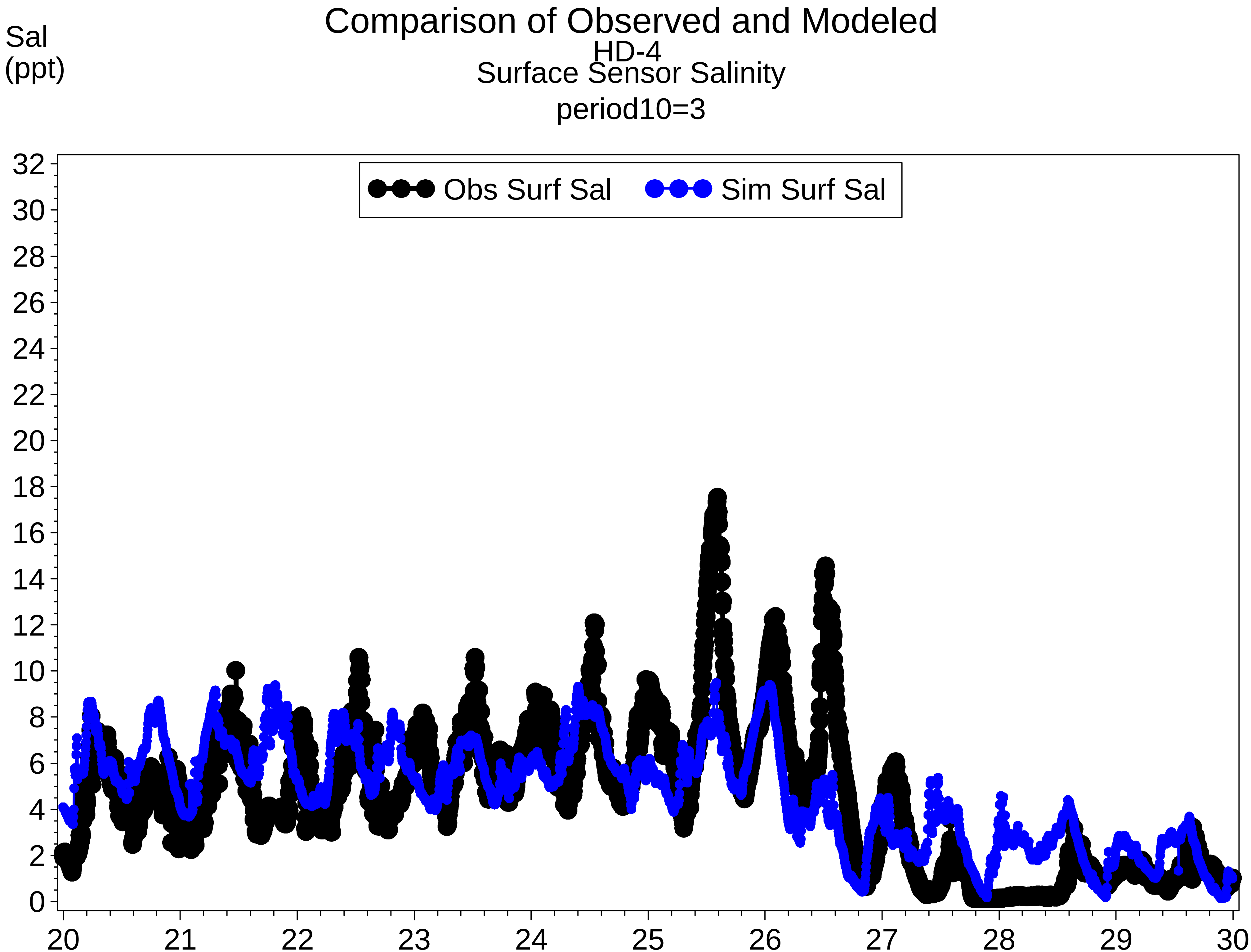
19
20

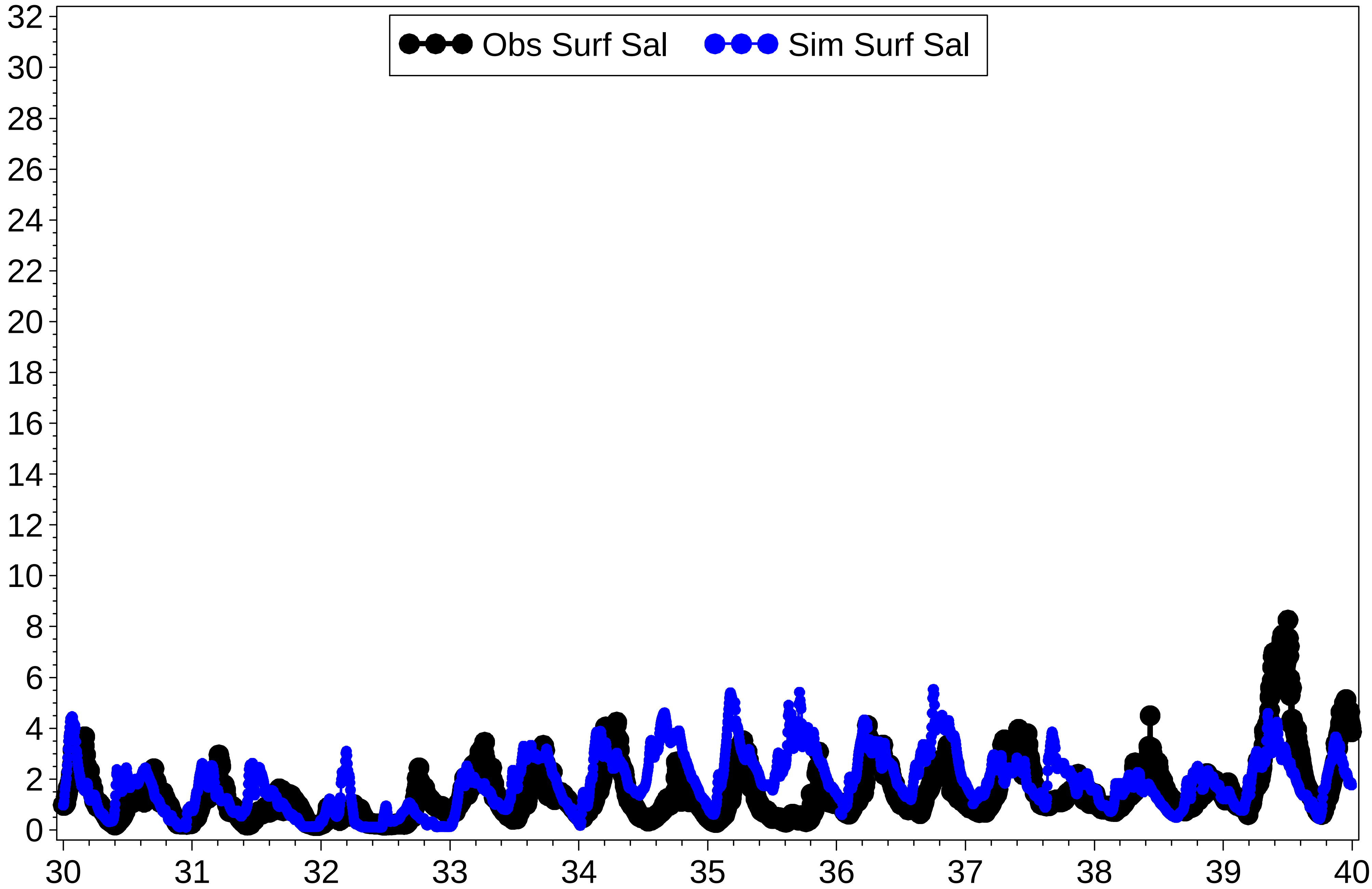


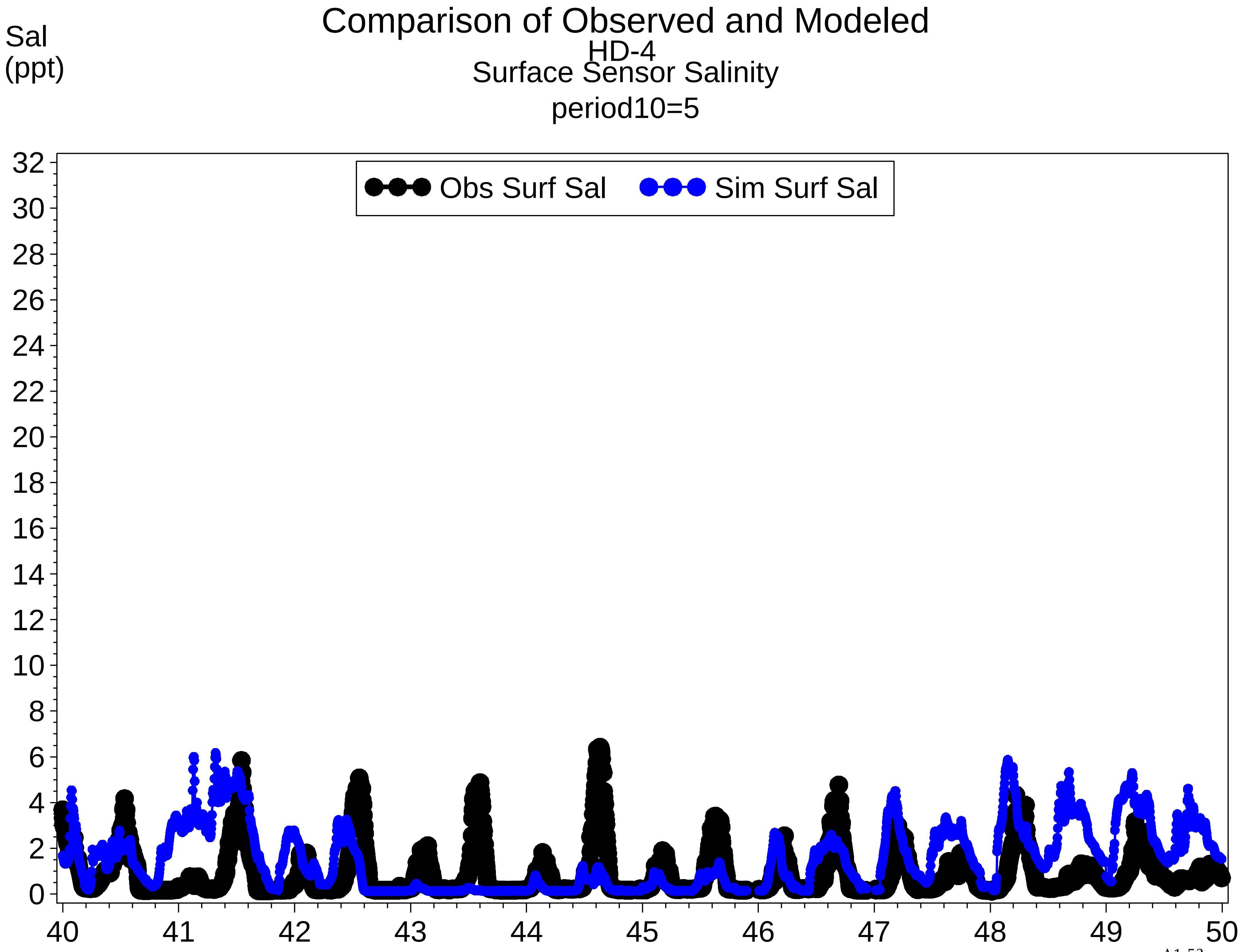
Sal
(ppt)
Comparison of Observed and Modeled
HD-4
Surface Sensor Salinity
period10=3
Obs Surf Sal
Sim Surf Sal
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
20
21
22
23
24
25
26
27
28
29
30

Sal
(ppt)

Comparison of Observed and Modeled
HD-4
Surface Sensor Salinity

period10=4




Comparison of Observed and Modeled
HD-4
Surface Sensor Salinity
period10=5
Sal
(ppt)
Obs Surf Sal
Sim Surf Sal
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
40
41
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43
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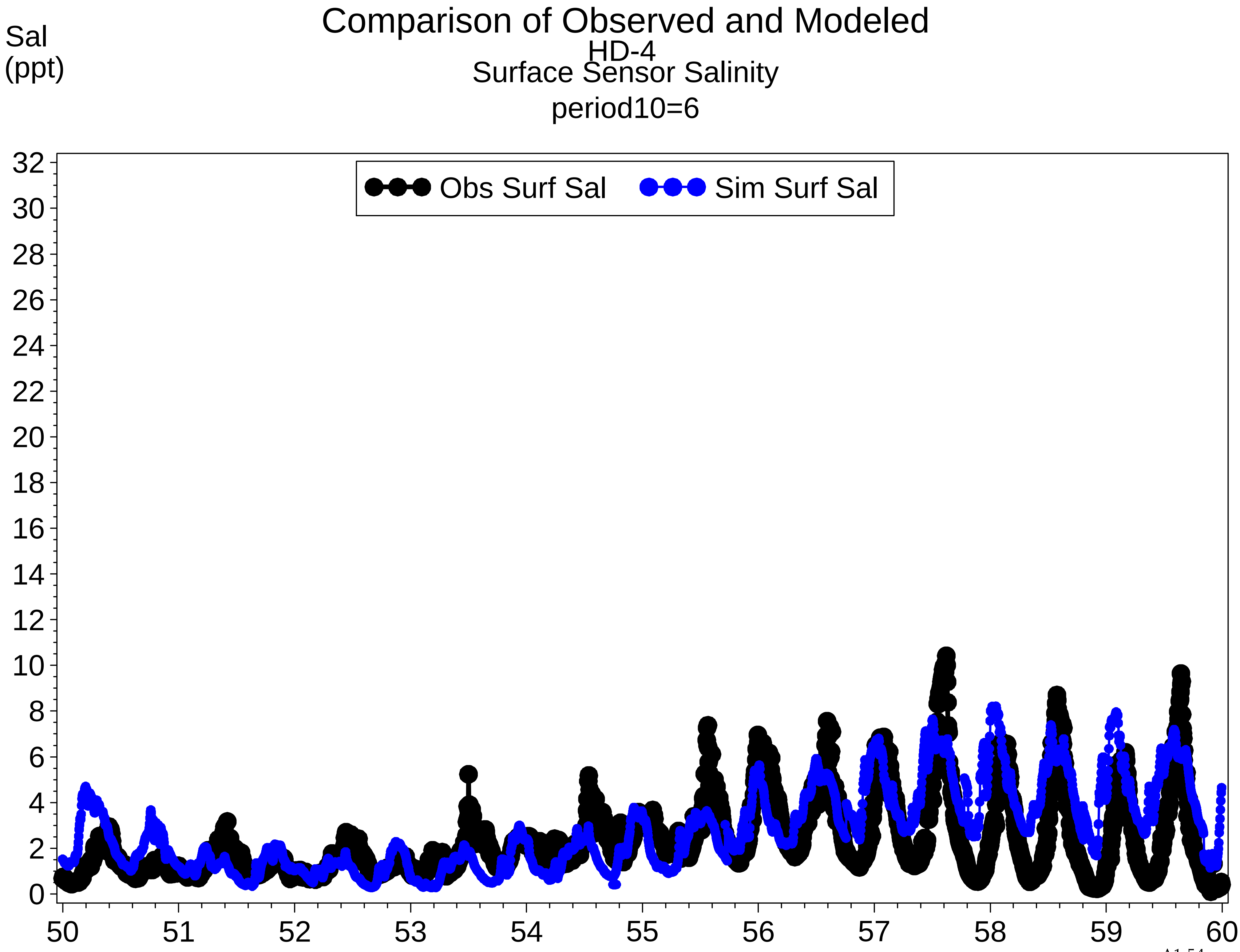
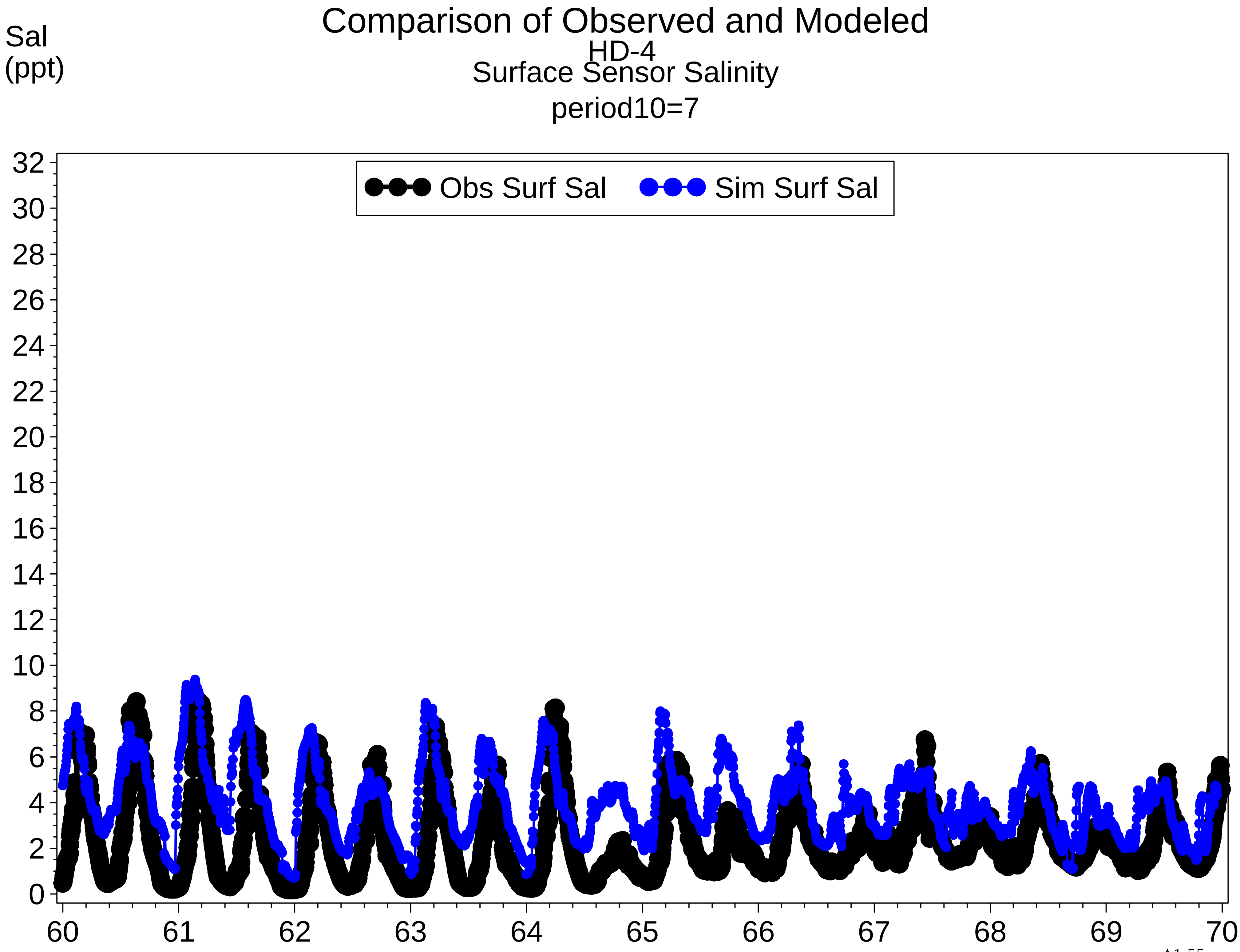
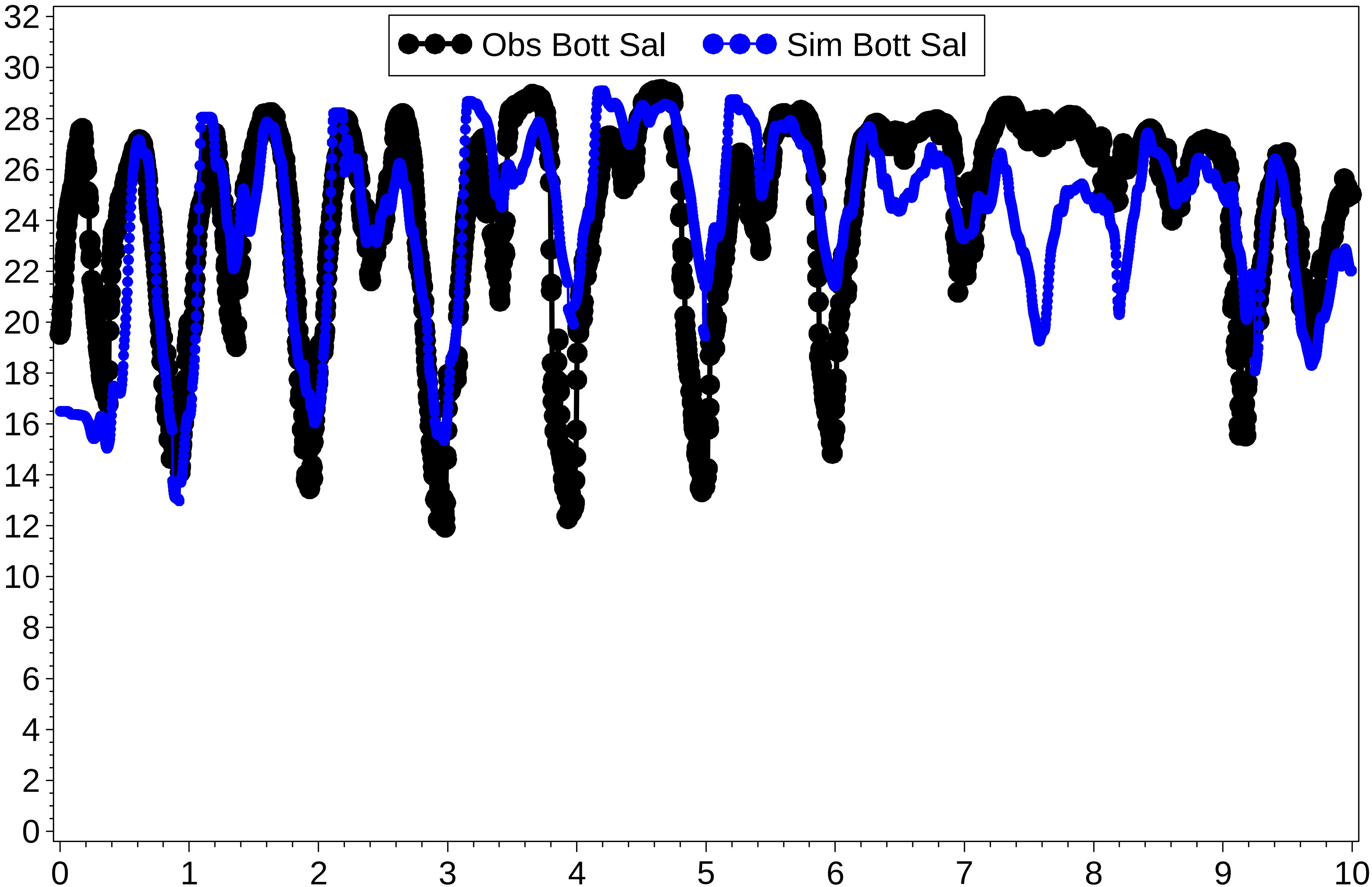


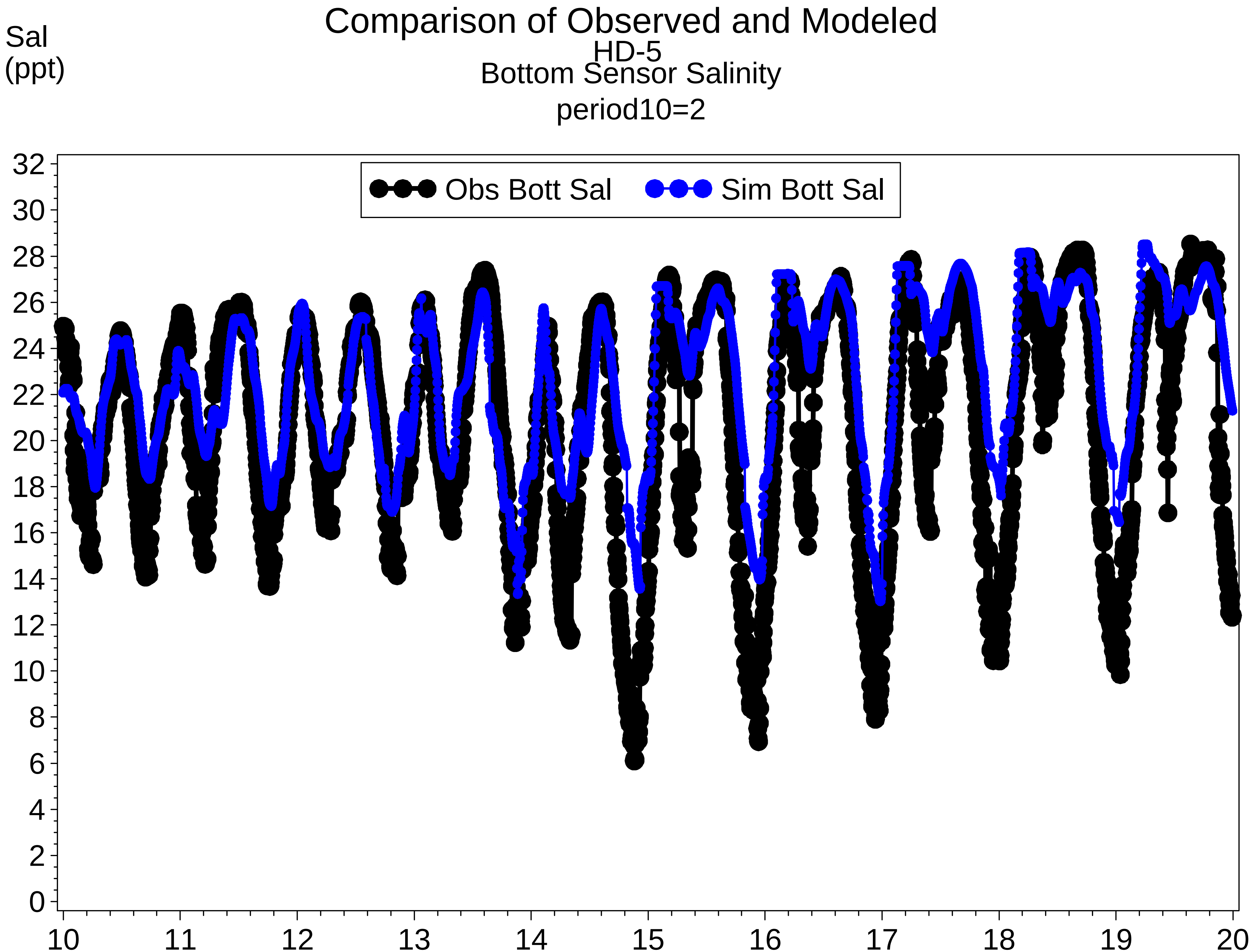
Sal
(ppt)
Comparison of Observed and Modeled
HD-4
Surface Sensor Salinity
period10=6
Obs Surf Sal
Sim Surf Sal
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
50
51
52
53
54
55
56
57
58
59
60


Sal
(ppt)
Comparison of Observed and Modeled
HD-4
Surface Sensor Salinity
period10=7
Obs Surf Sal
Sim Surf Sal
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
60
61
62
63
64
65
66
67
68
69
70

Sal
(ppt)

Comparison of Observed and Modeled
HD-5
Bottom Sensor Salinity
period10=1




Comparison of Observed and Modeled
HD-5
Bottom Sensor Salinity
period10=2
Sal
(ppt)
Obs Bott Sal
Sim Bott Sal
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
10
11
12
13
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17
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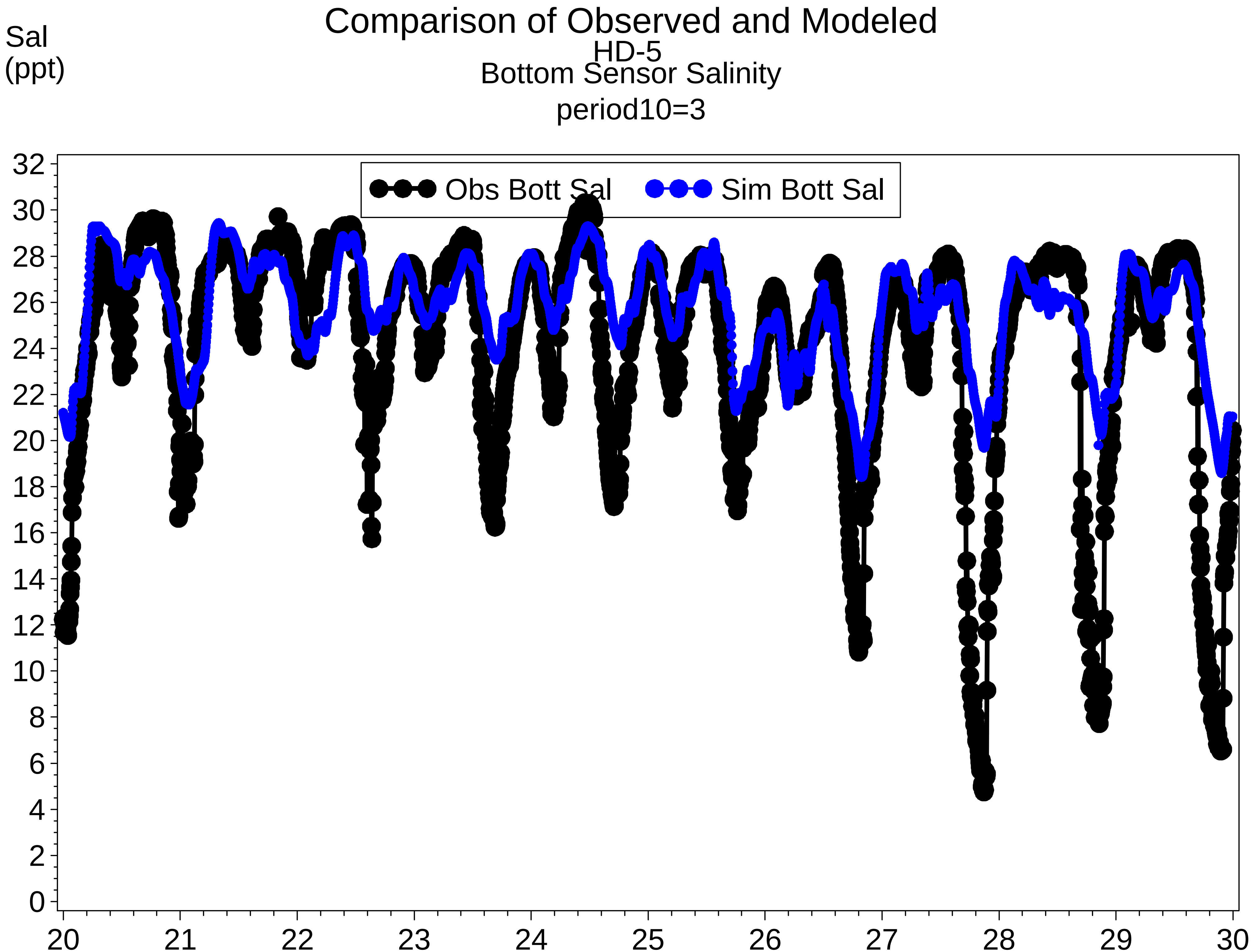
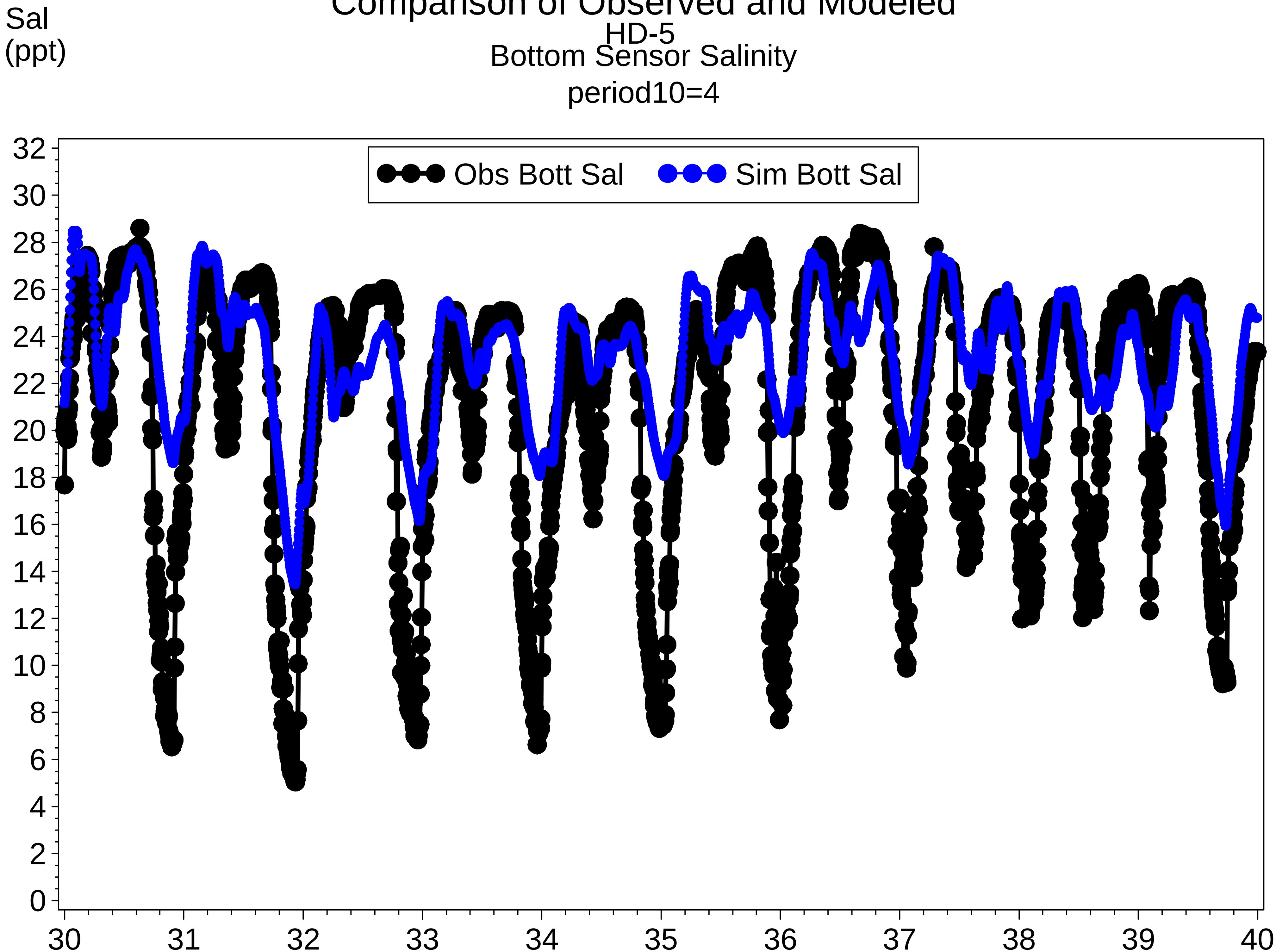
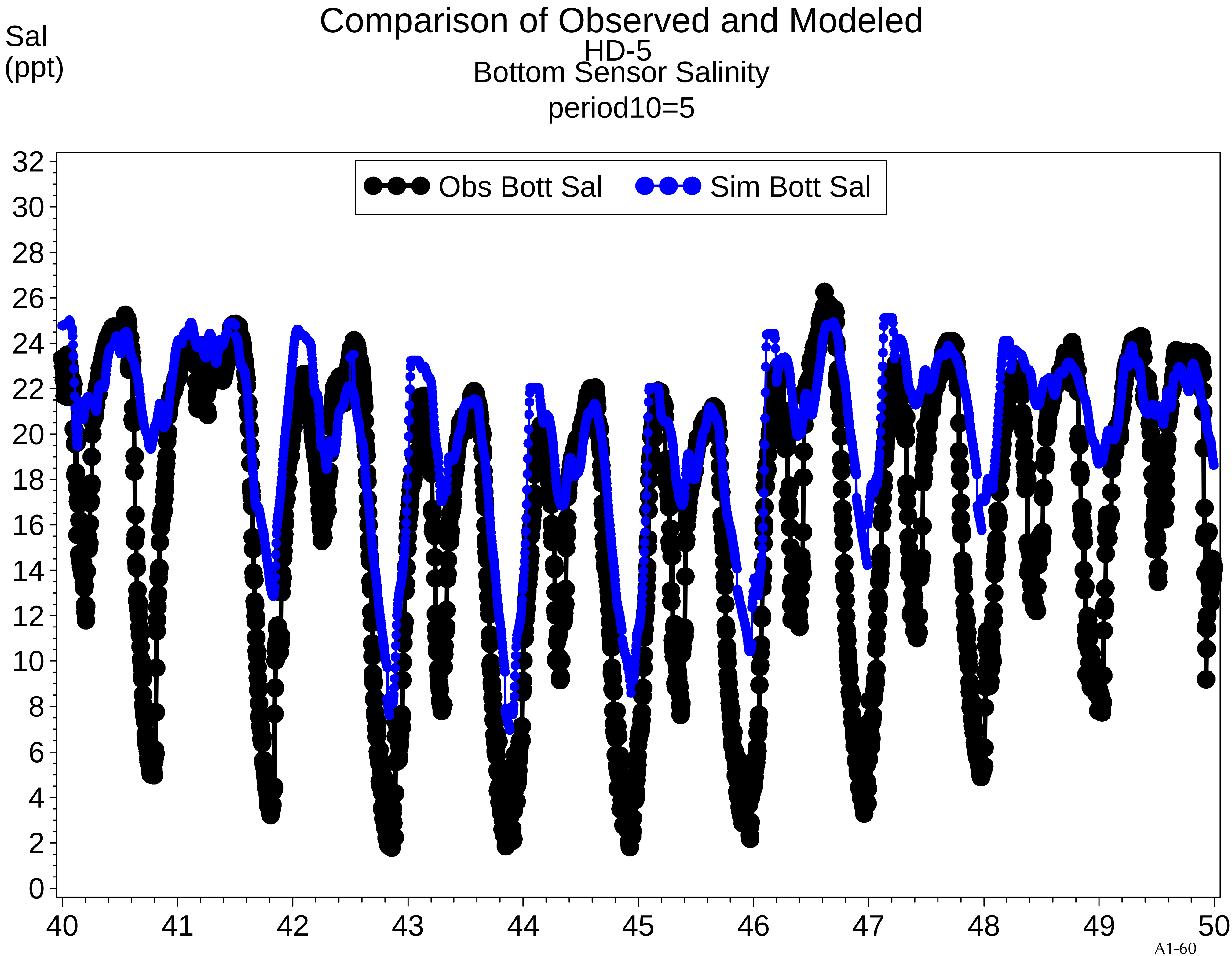
19
20



Comparison of Observed and Modeled
HD-5
Bottom Sensor Salinity
period10=3
Sal
(ppt)
Obs Bott Sal
Sim Bott Sal
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
20
21
22
23
24
25
26
27
28
29
30

Comparison of Observed and Modeled
HD-5
Bottom Sensor Salinity
period10=4





Comparison of Observed and Modeled
HD-5
Bottom Sensor Salinity
period10=5
Sal
(ppt)
Obs Bott Sal
Sim Bott Sal
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
40
41
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43
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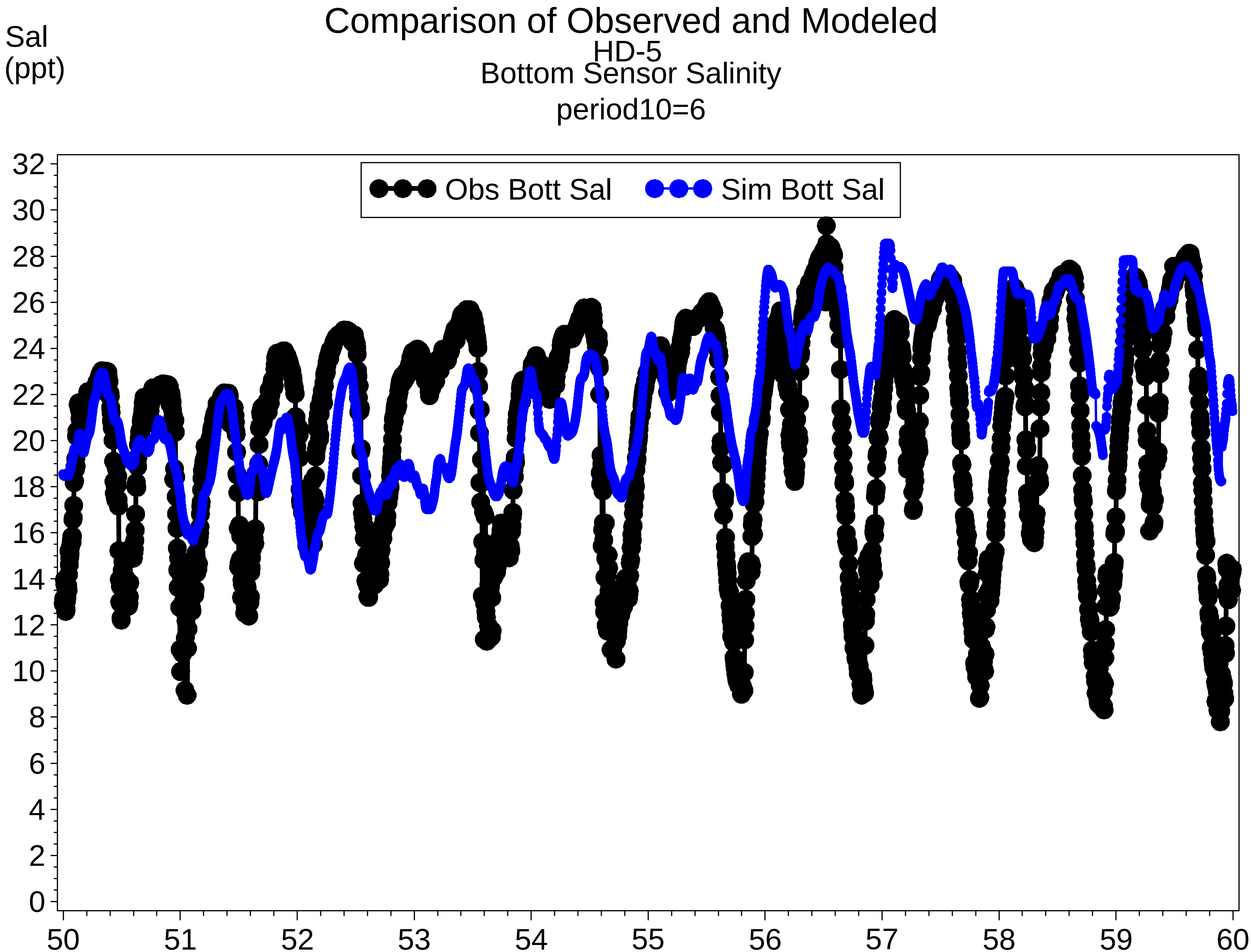

Comparison of Observed and Modeled
HD-5
Bottom Sensor Salinity
period10=6
Sal
(ppt)
Obs Bott Sal
Sim Bott Sal
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
50
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53
54
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57
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59
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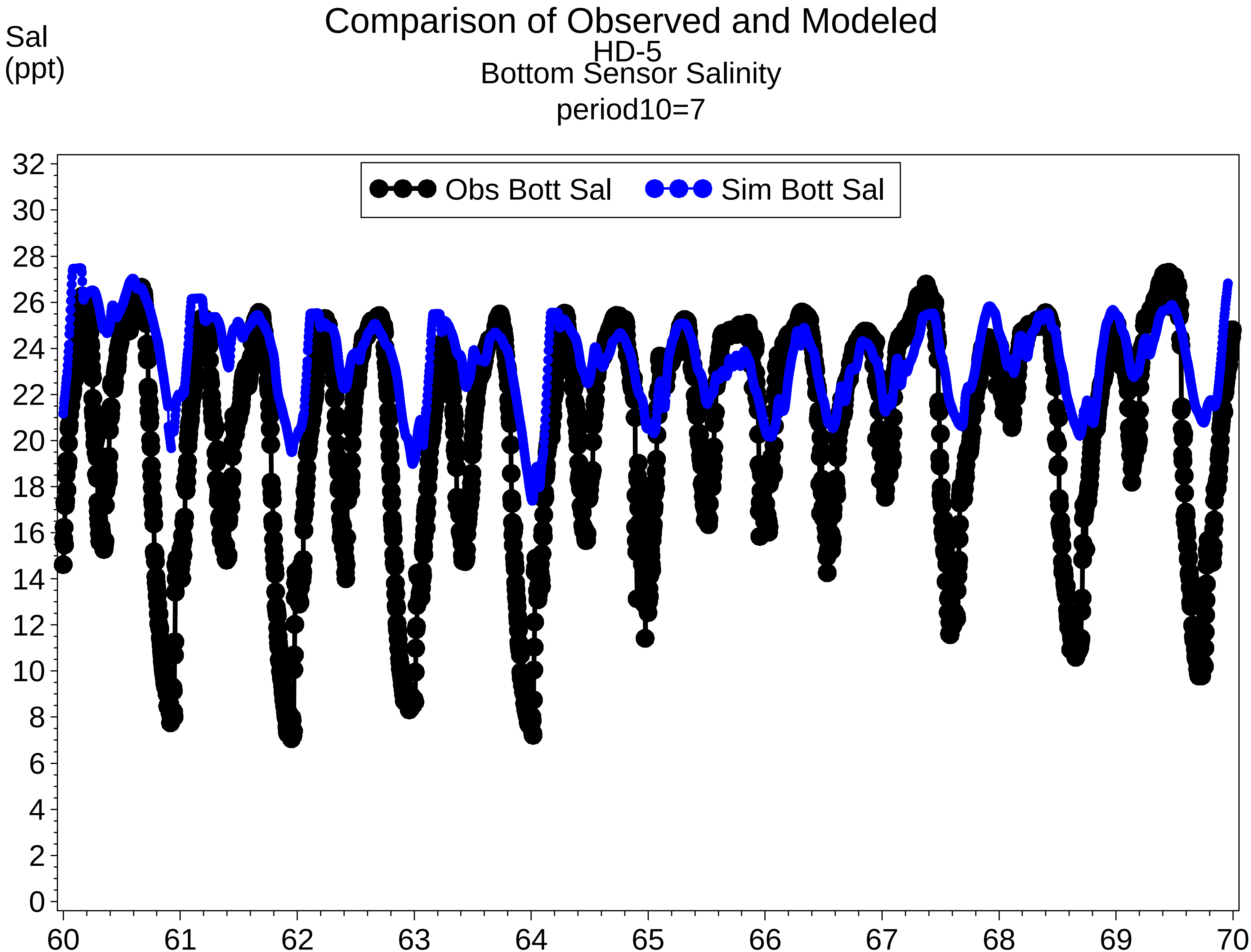
Sal
(ppt)
Comparison of Observed and Modeled
HD-5
Bottom Sensor Salinity
period10=7
Obs Bott Sal
Sim Bott Sal
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
60
61
62
63
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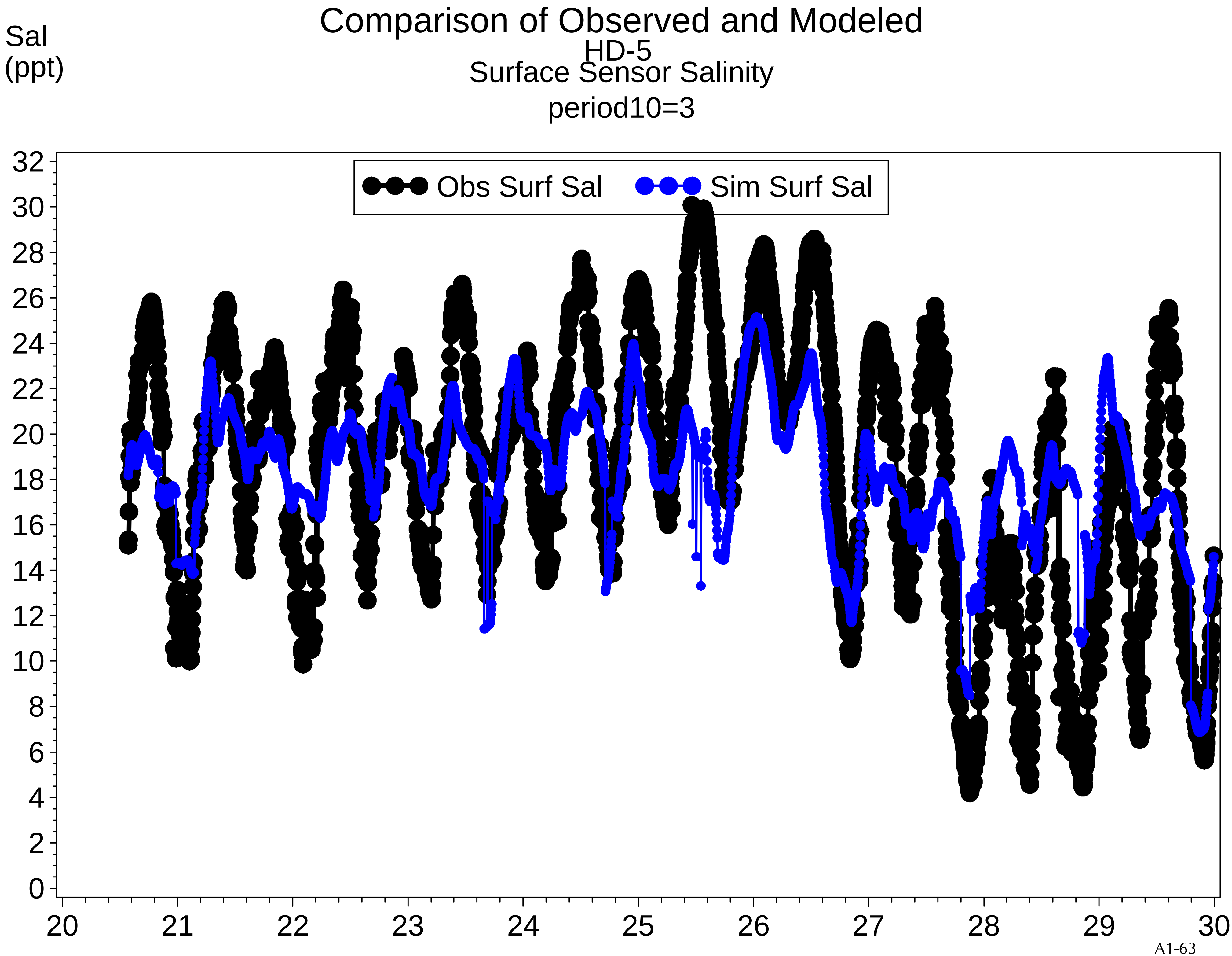

Comparison of Observed and Modeled
HD-5
Surface Sensor Salinity
period10=3
Sal
(ppt)
Obs Surf Sal
Sim Surf Sal
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
20
21
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23
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27
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29
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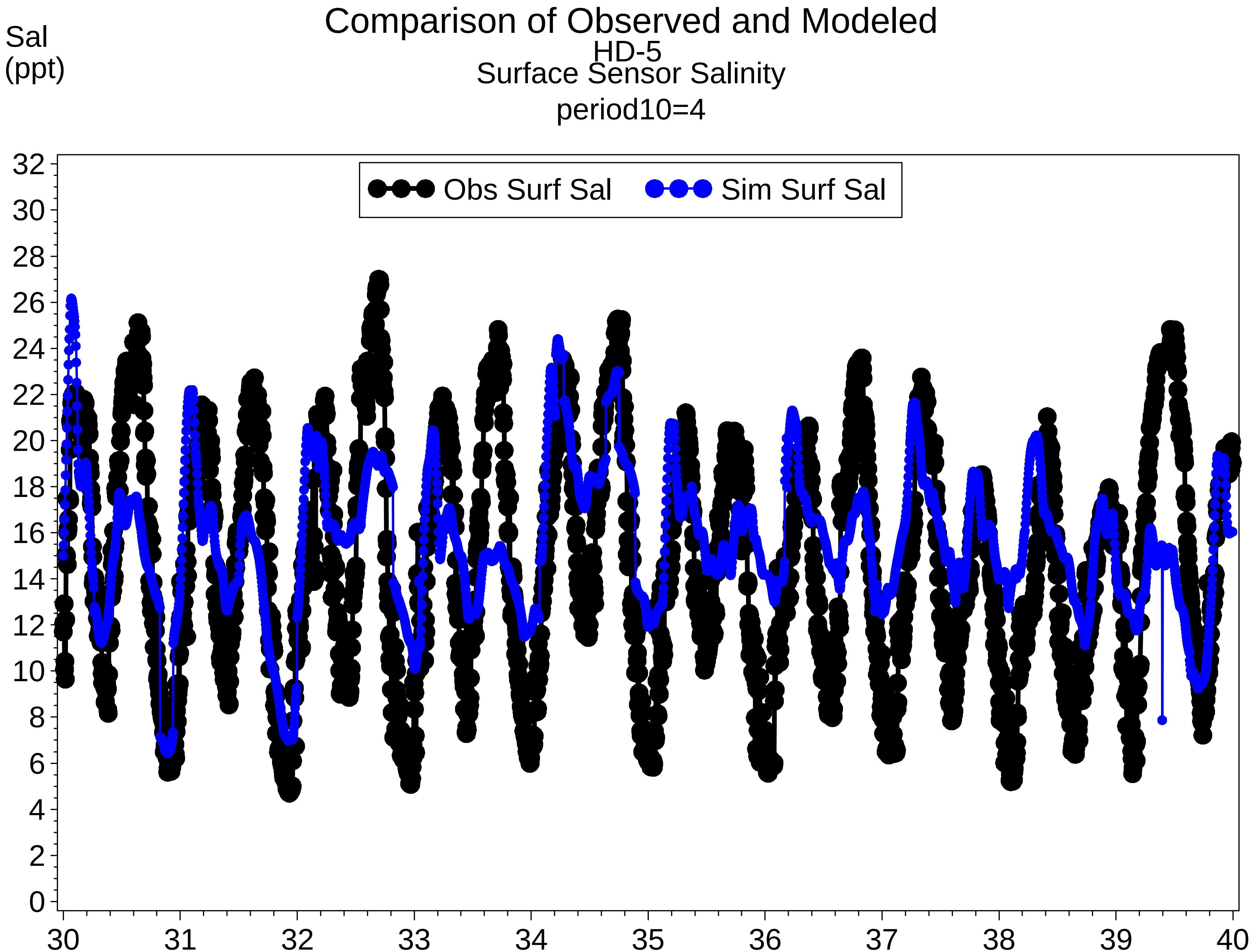

Sal
(ppt)
Comparison of Observed and Modeled
HD-5
Surface Sensor Salinity
period10=4
Obs Surf Sal
Sim Surf Sal
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
30
31
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33
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39
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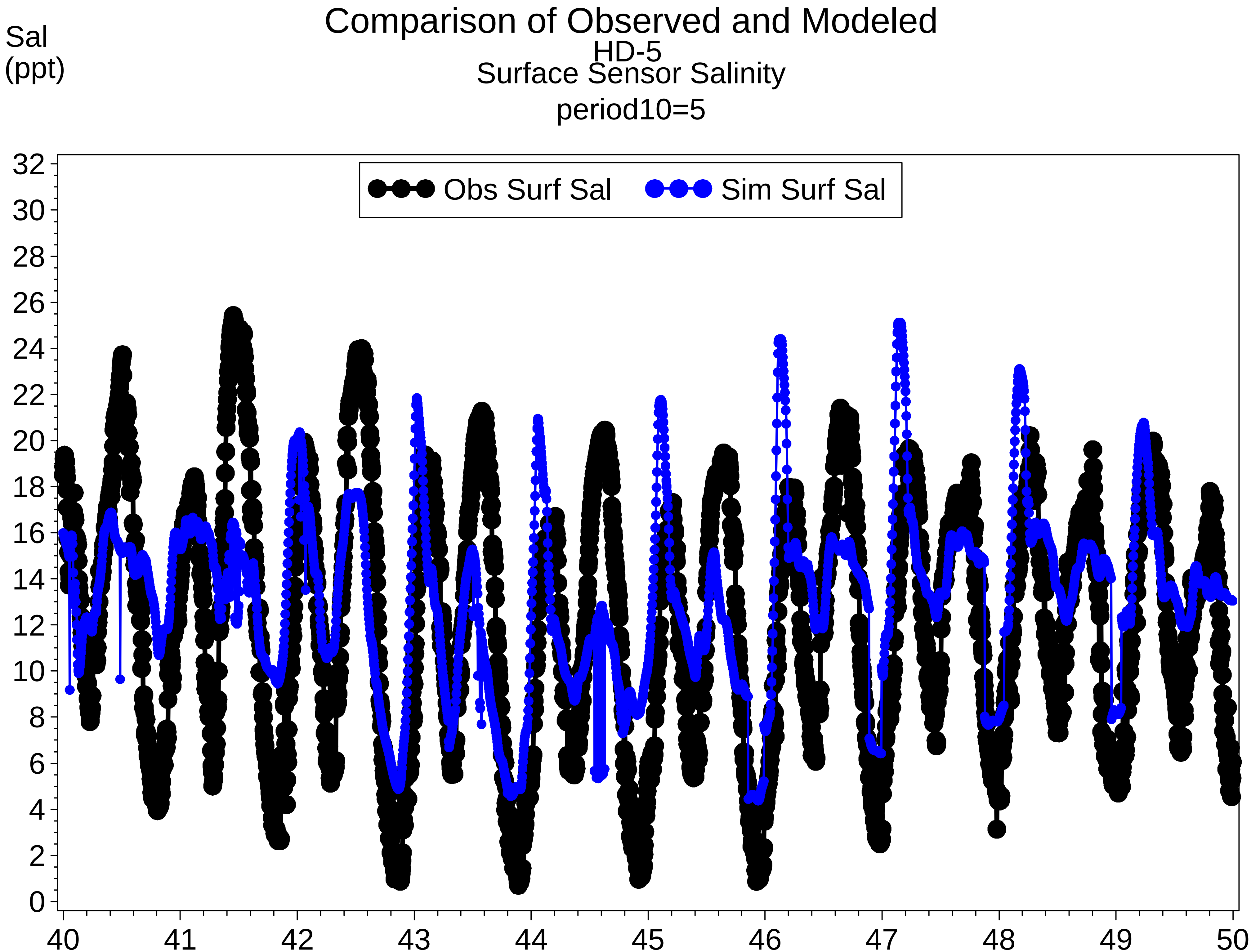

Sal
(ppt)
Comparison of Observed and Modeled
HD-5
Surface Sensor Salinity
period10=5
Obs Surf Sal
Sim Surf Sal
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
40
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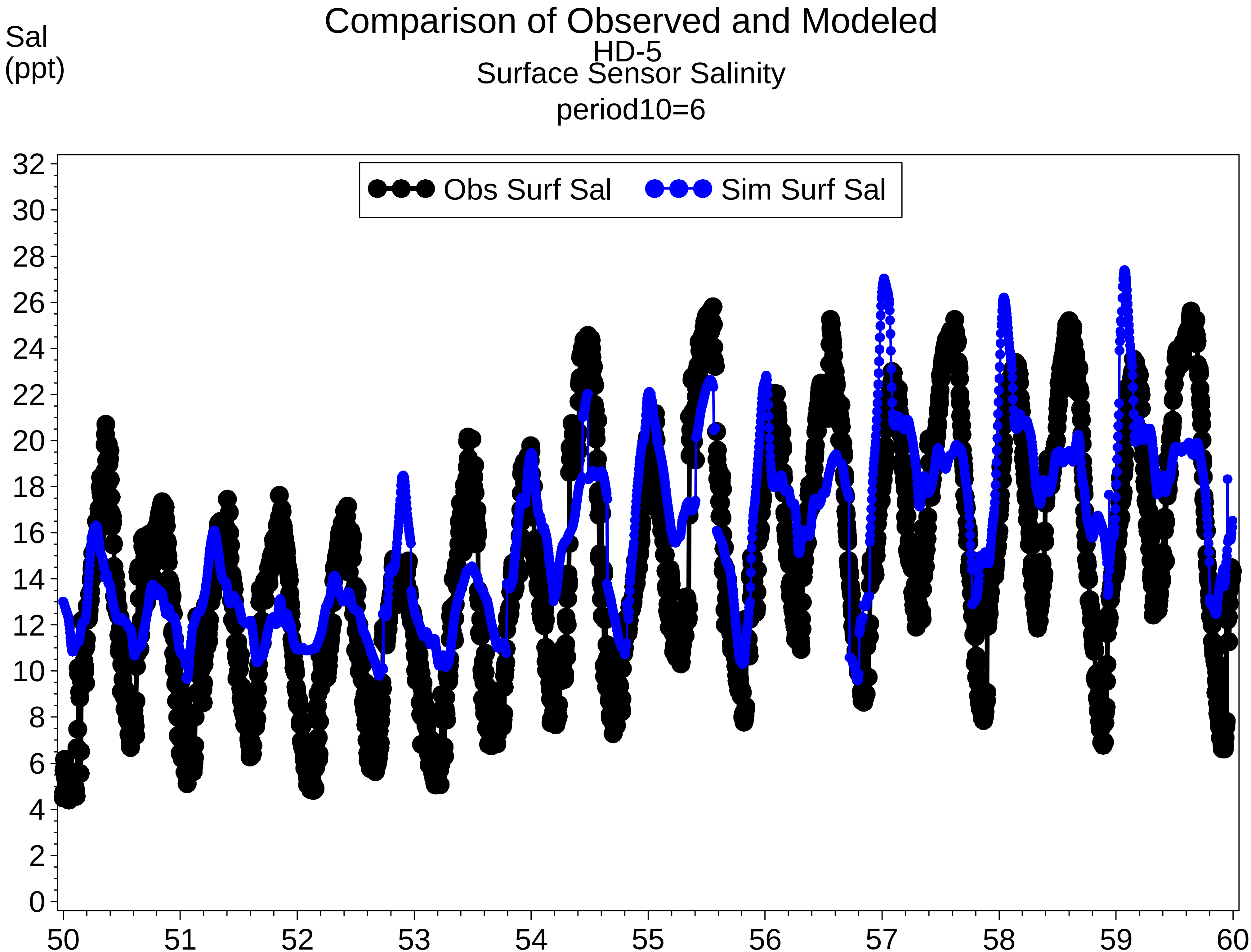
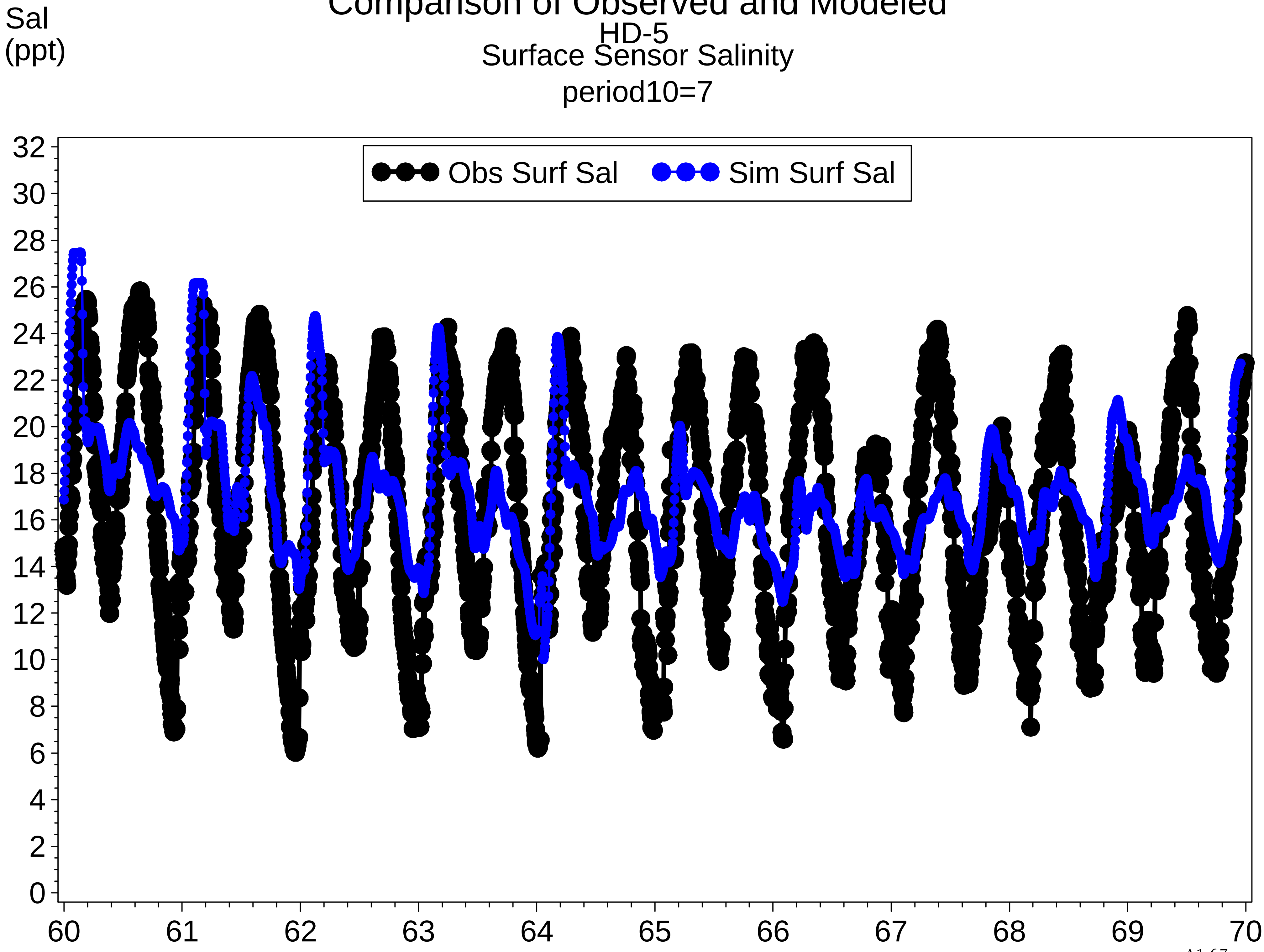
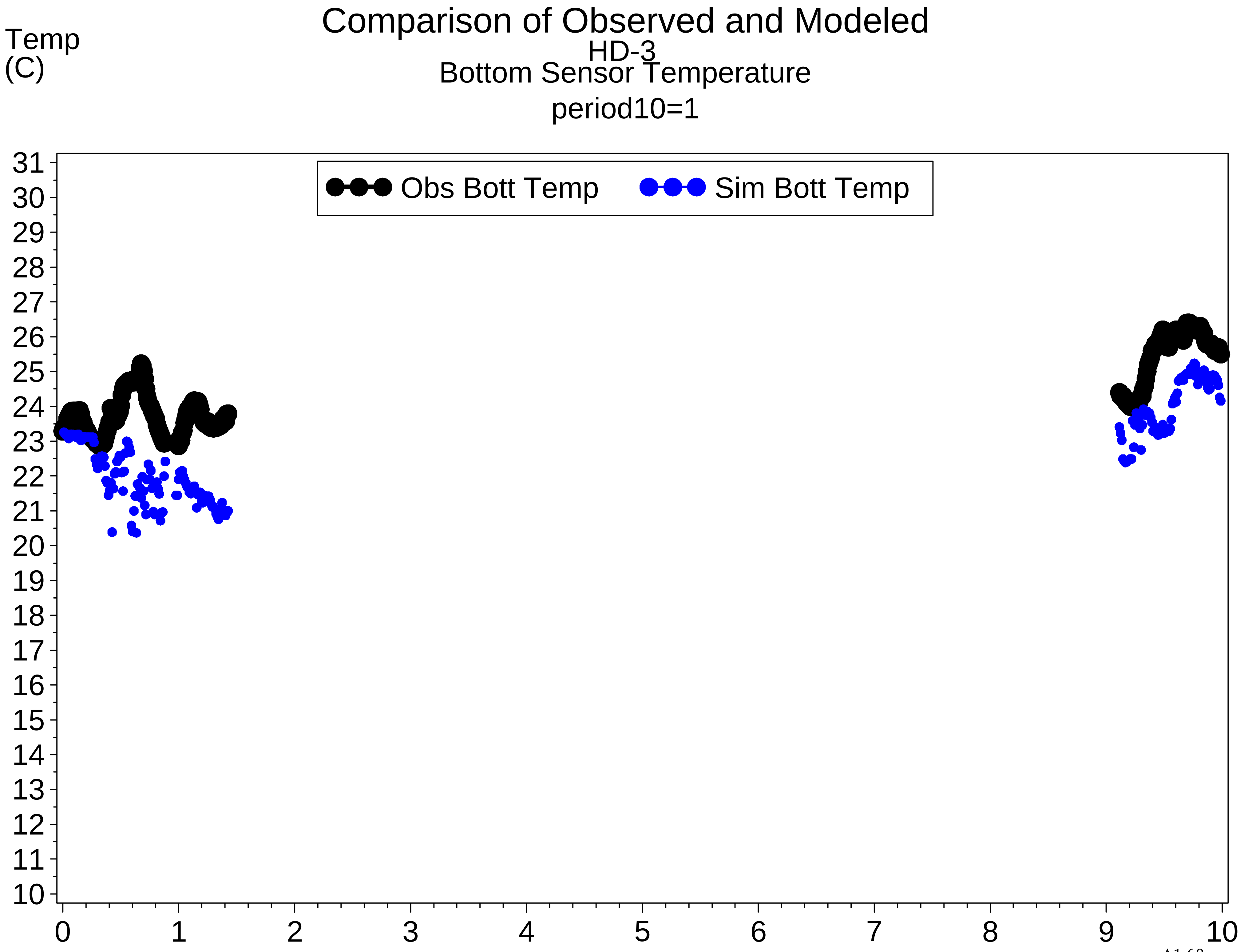


Comparison of Observed and Modeled
HD-5
Surface Sensor Salinity
period10=6
Sal
(ppt)
Obs Surf Sal
Sim Surf Sal
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
50
51
52
53
54
55
56
57
58
59
60

Comparison of Observed and Modeled
HD-5
Surface Sensor Salinity
period10=7

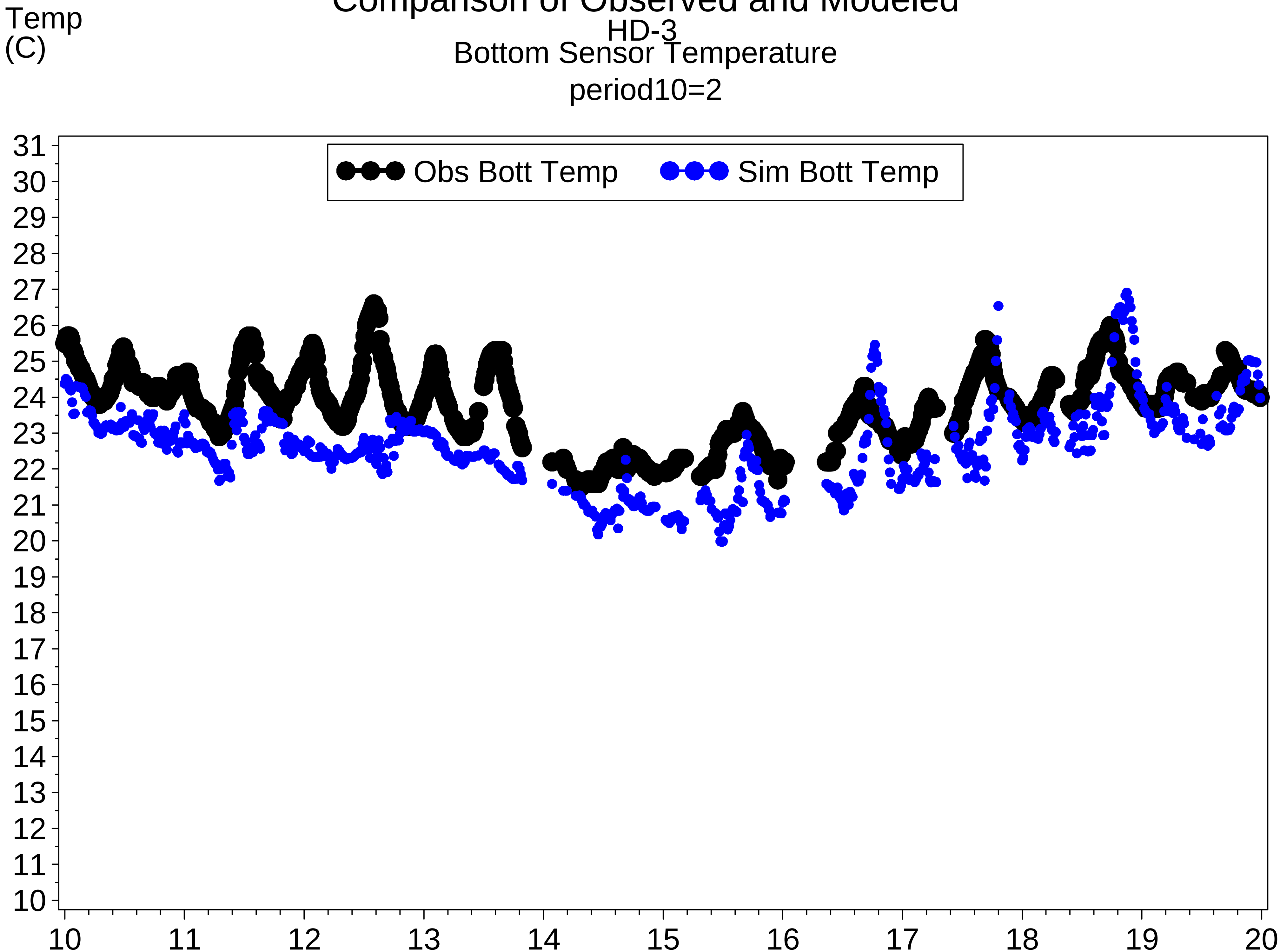


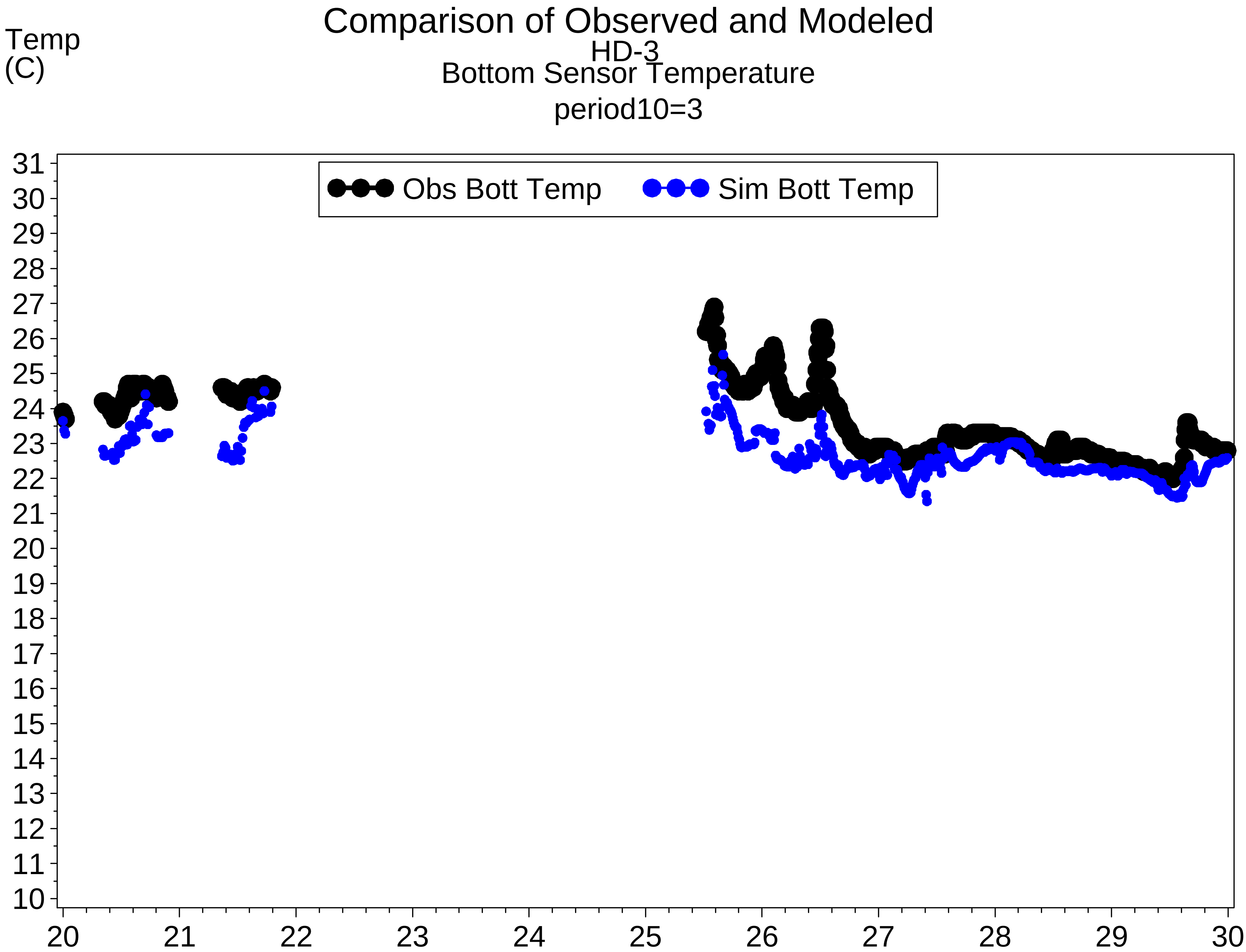


Comparison of Observed and Modeled
HD-3
Bottom Sensor Temperature
period10=1
Temp
(C)
Obs Bott Temp
Sim Bott Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
0
1
2
3
4
5
6
7
8
9
10

Comparison of Observed and Modeled

HD-3
Bottom Sensor Temperature
period10=2





Comparison of Observed and Modeled
HD-3
Bottom Sensor Temperature
period10=3
Temp
(C)
Obs Bott Temp
Sim Bott Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
20
21
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23
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27
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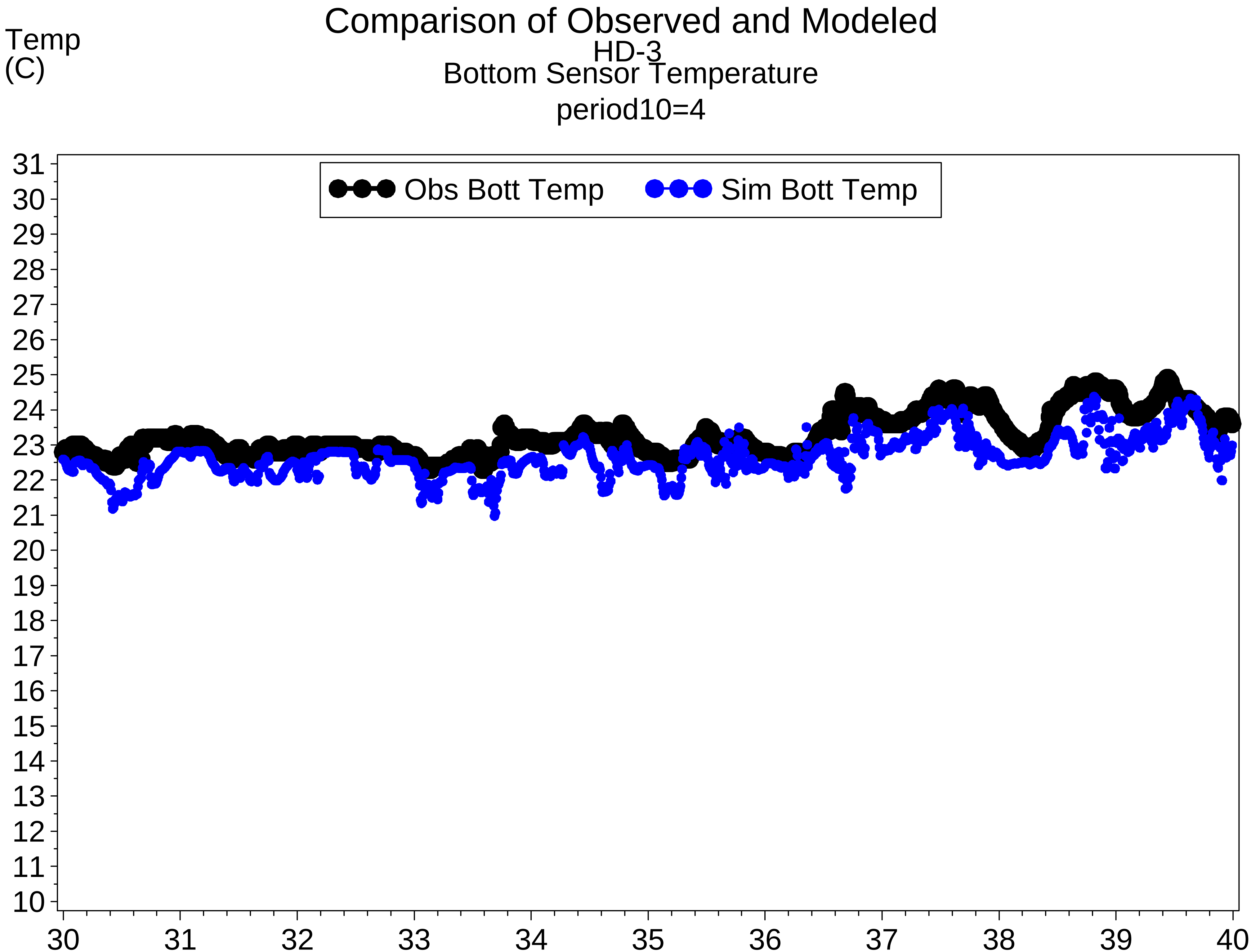
29
30



Comparison of Observed and Modeled
HD-3
Bottom Sensor Temperature
period10=4
Temp
(C)
Obs Bott Temp
Sim Bott Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
30
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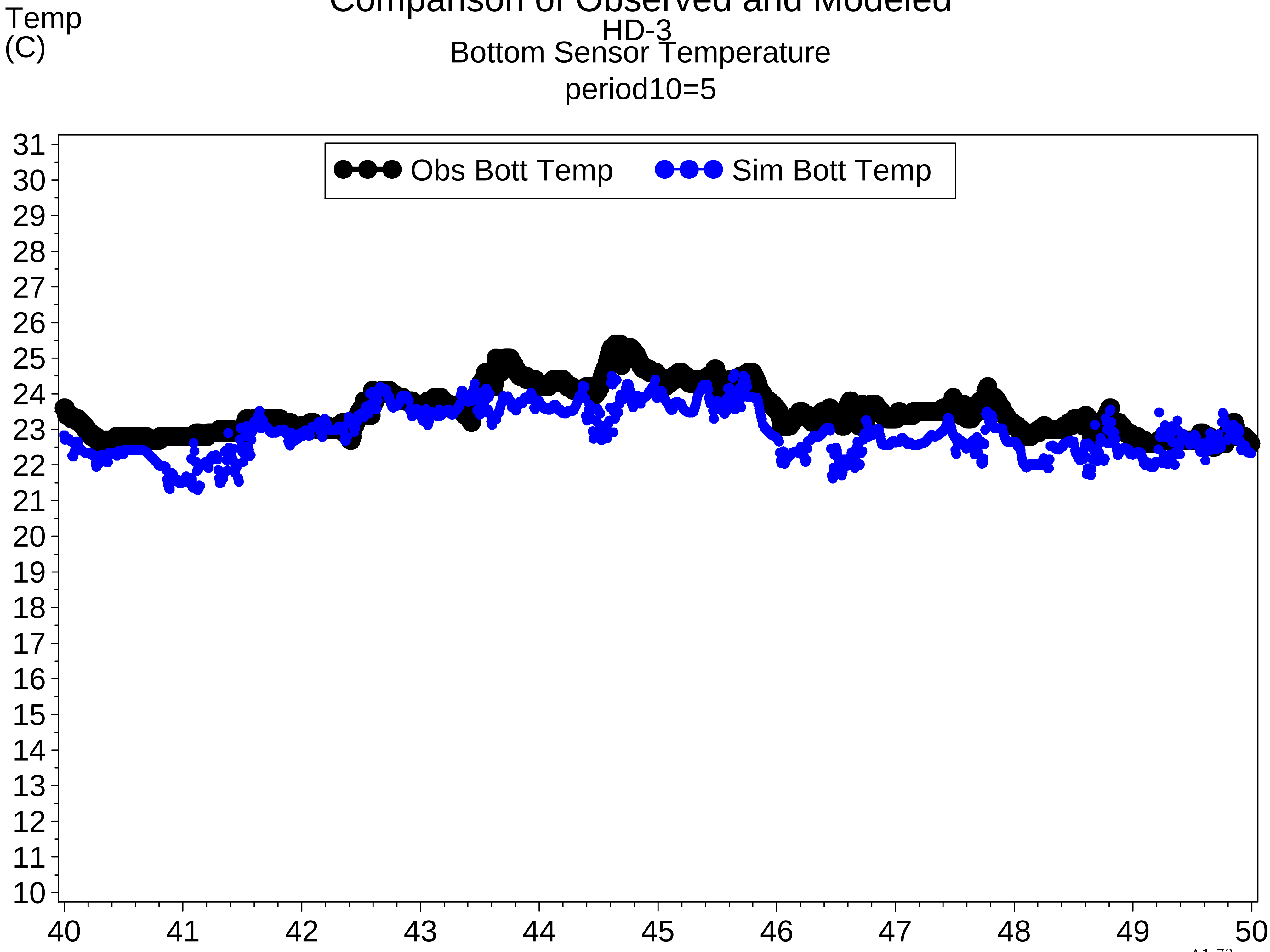
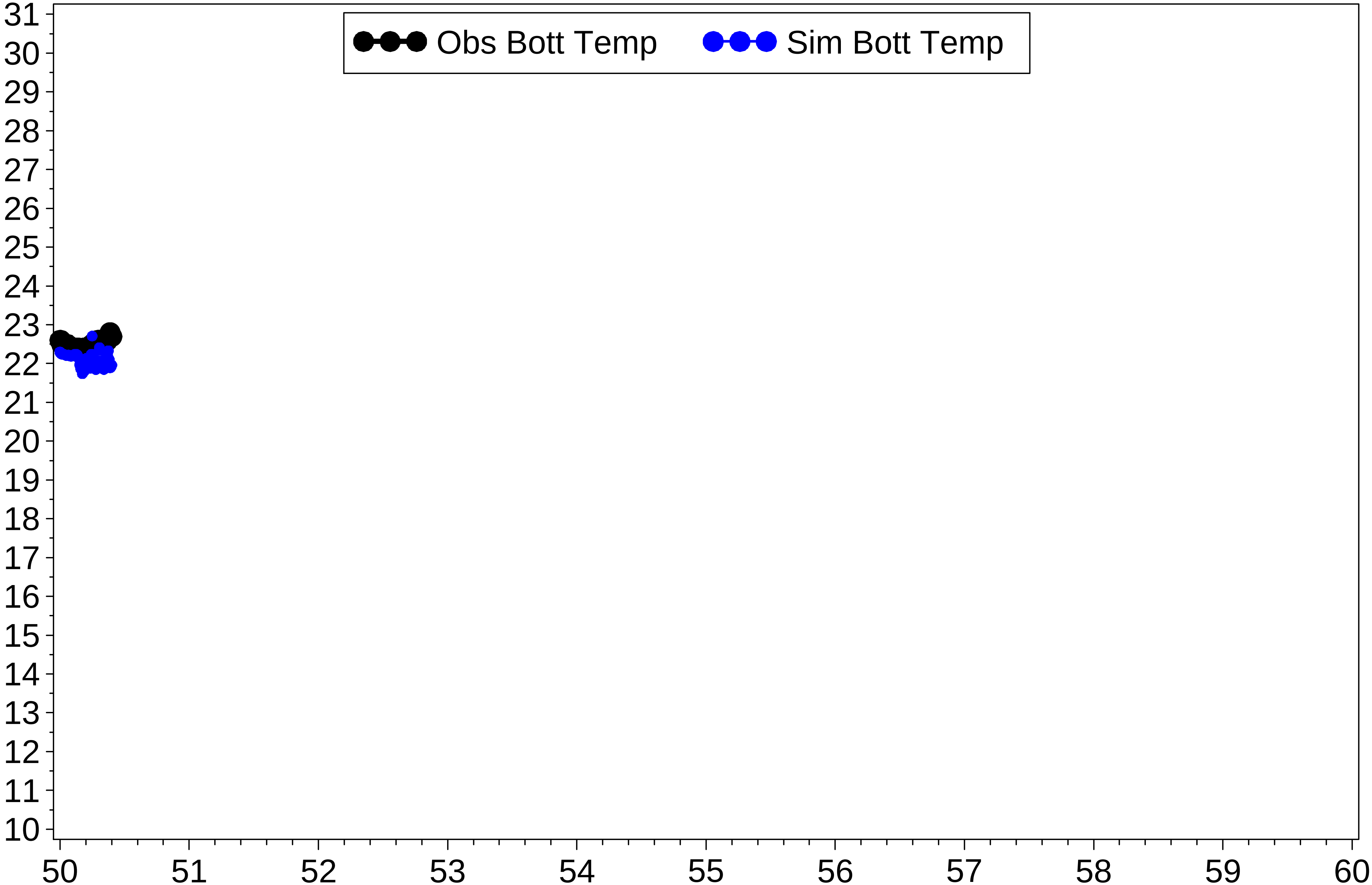
33
34
35
36
37
38
39
40

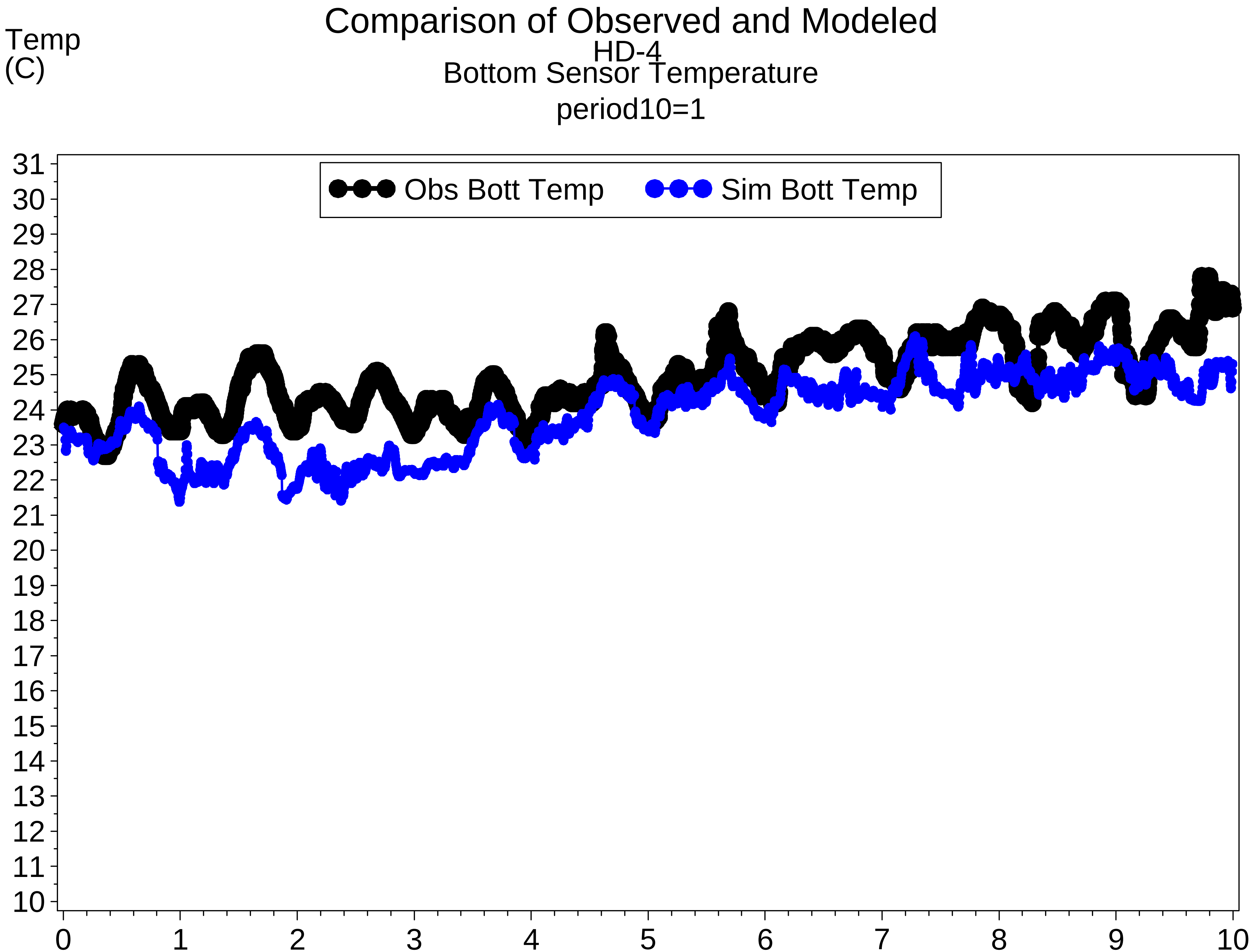
Comparison of Observed and Modeled
HD-3
Bottom Sensor Temperature
period10=5



Temp
(C)

Comparison of Observed and Modeled
HD-3
Bottom Sensor Temperature
period10=6




Comparison of Observed and Modeled
HD-4
Bottom Sensor Temperature
period10=1
Temp
(C)
Obs Bott Temp
Sim Bott Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
0
1
2
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4
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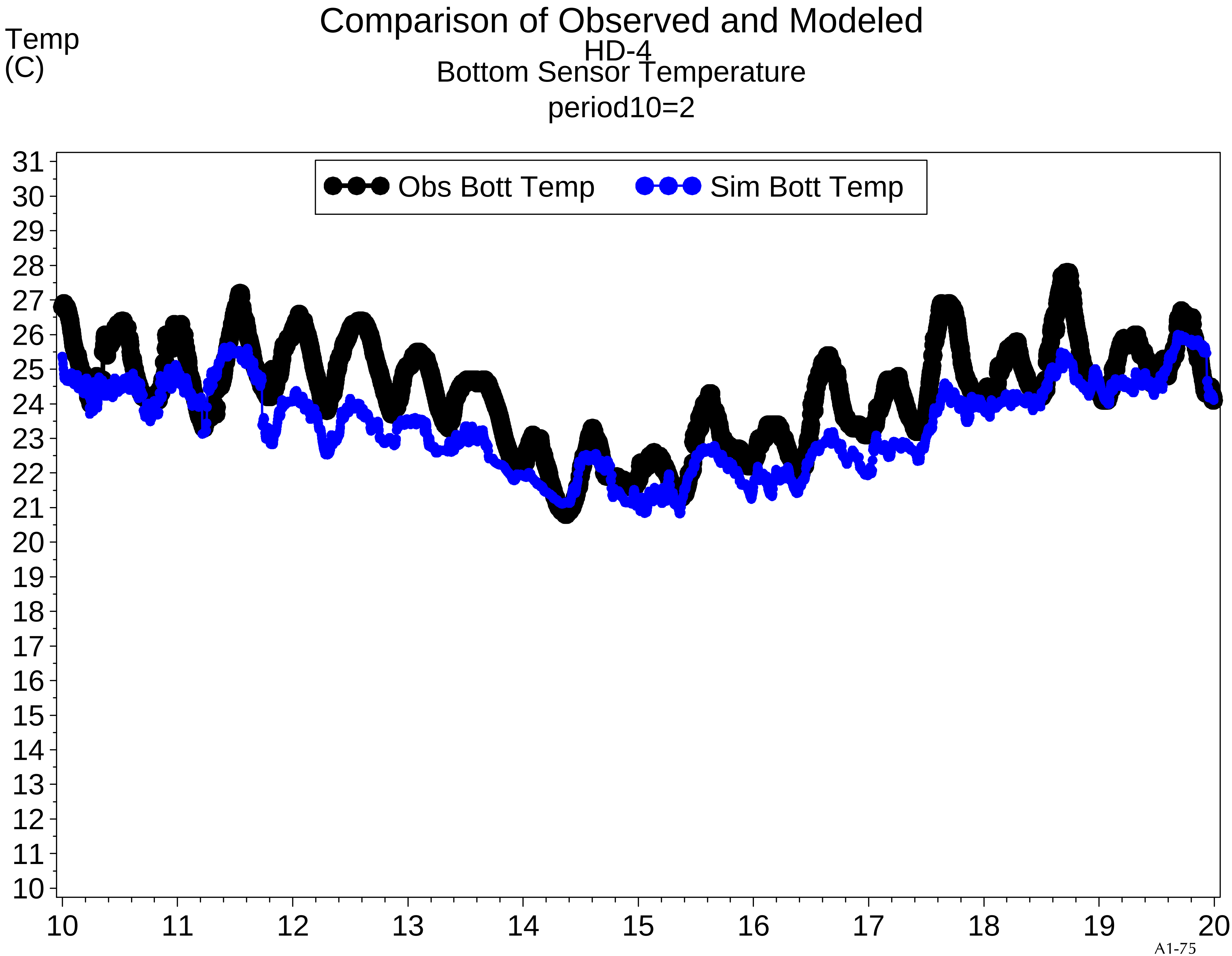
8
9
10


Comparison of Observed and Modeled
HD-4
Bottom Sensor Temperature
period10=2
Temp
(C)
Obs Bott Temp
Sim Bott Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
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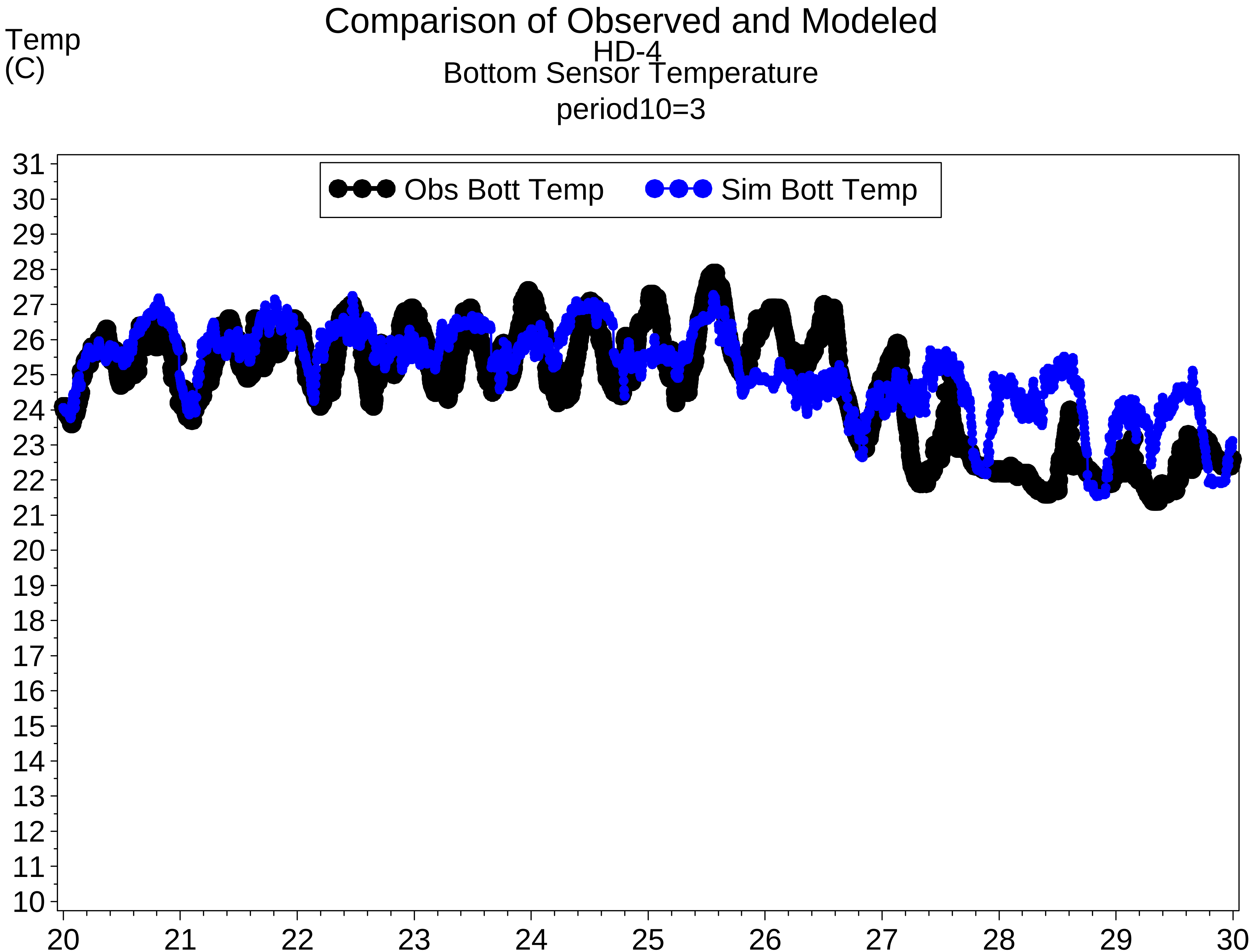
Comparison of Observed and Modeled
HD-4
Bottom Sensor Temperature
period10=3
Temp
(C)
Obs Bott Temp
Sim Bott Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
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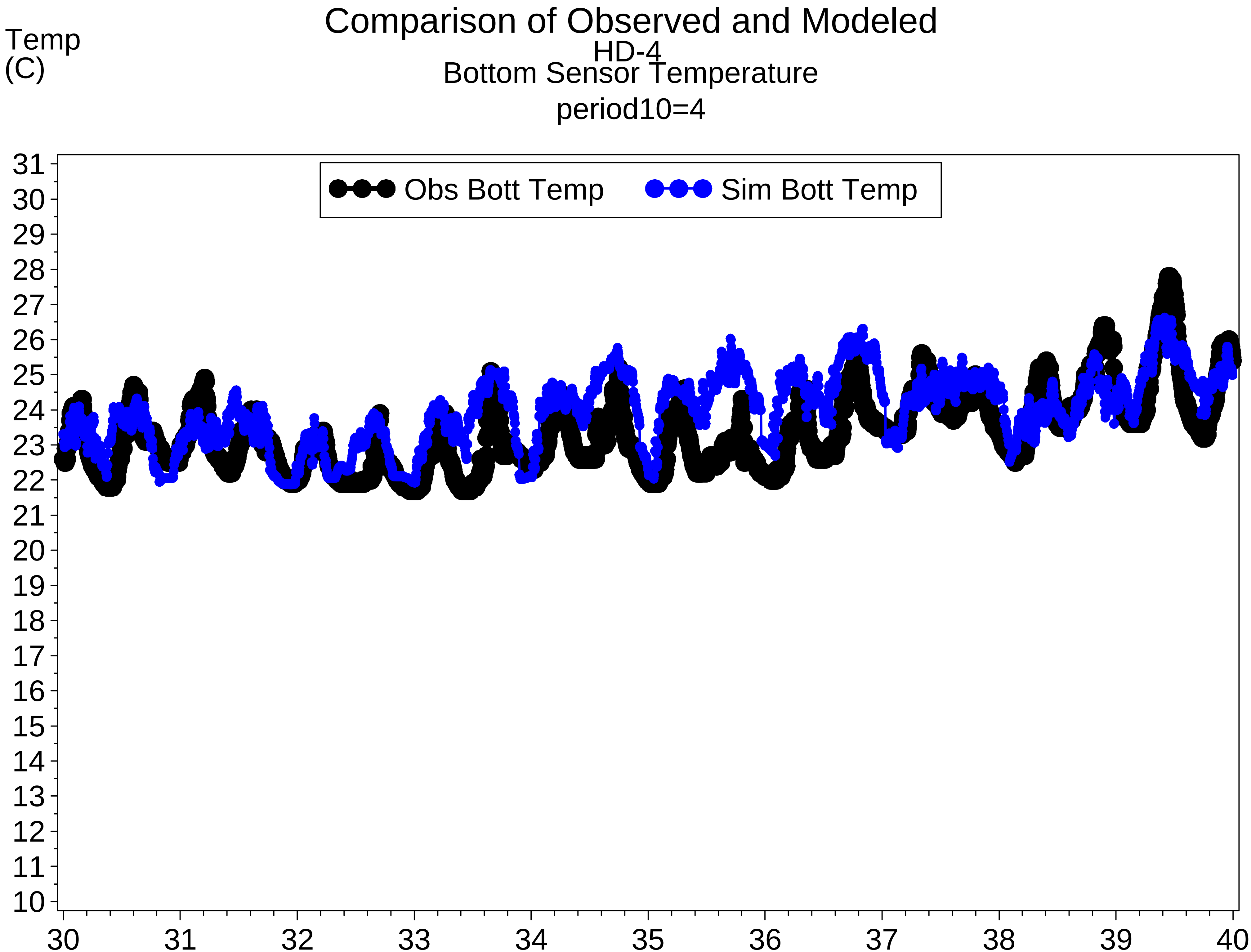
Temp
(C)
Comparison of Observed and Modeled
HD-4
Bottom Sensor Temperature
period10=4
Obs Bott Temp
Sim Bott Temp
31
30
29
28
27
26
25
24
23
22
21
20
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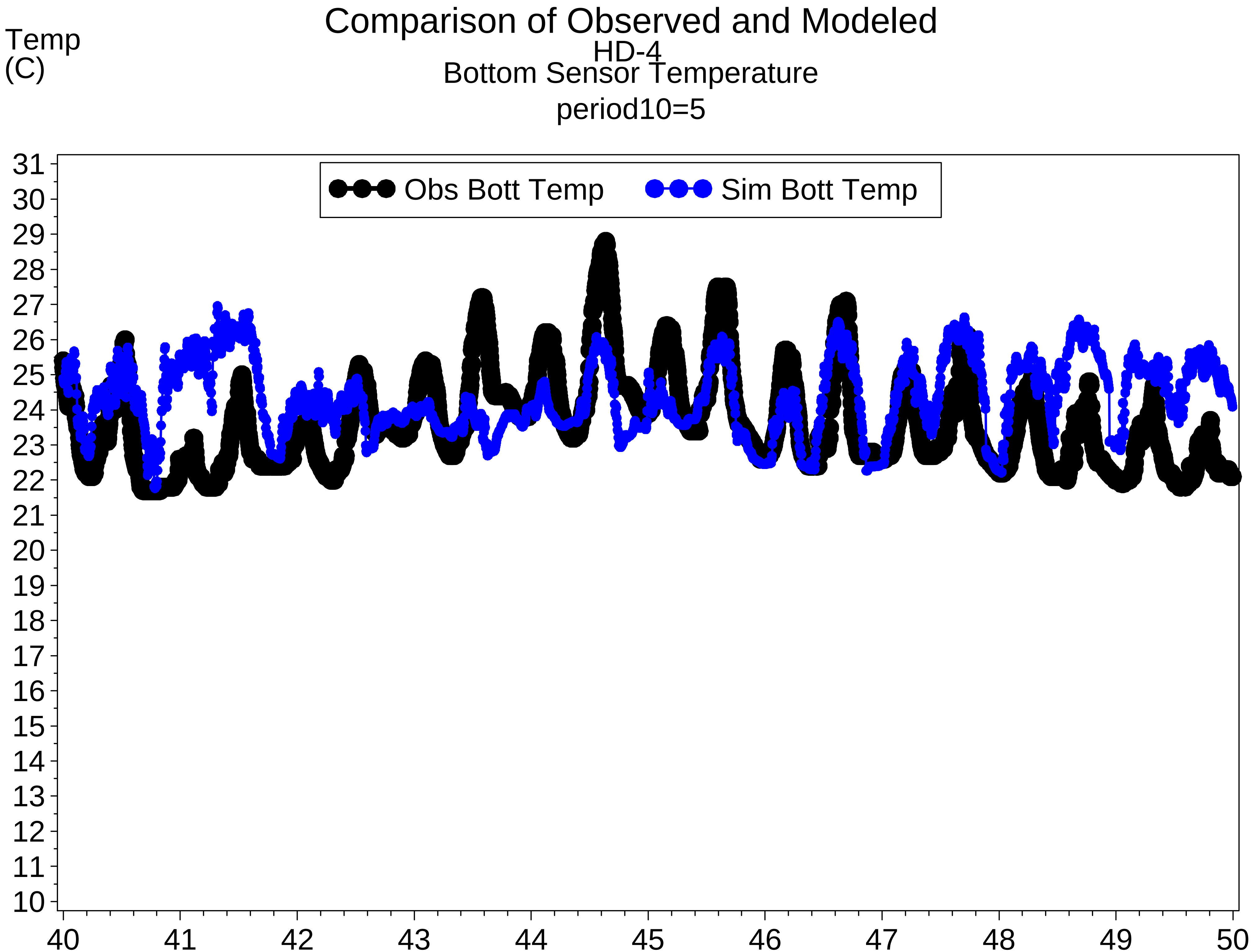
Comparison of Observed and Modeled
HD-4
Bottom Sensor Temperature
period10=5
Temp
(C)
Obs Bott Temp
Sim Bott Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
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41
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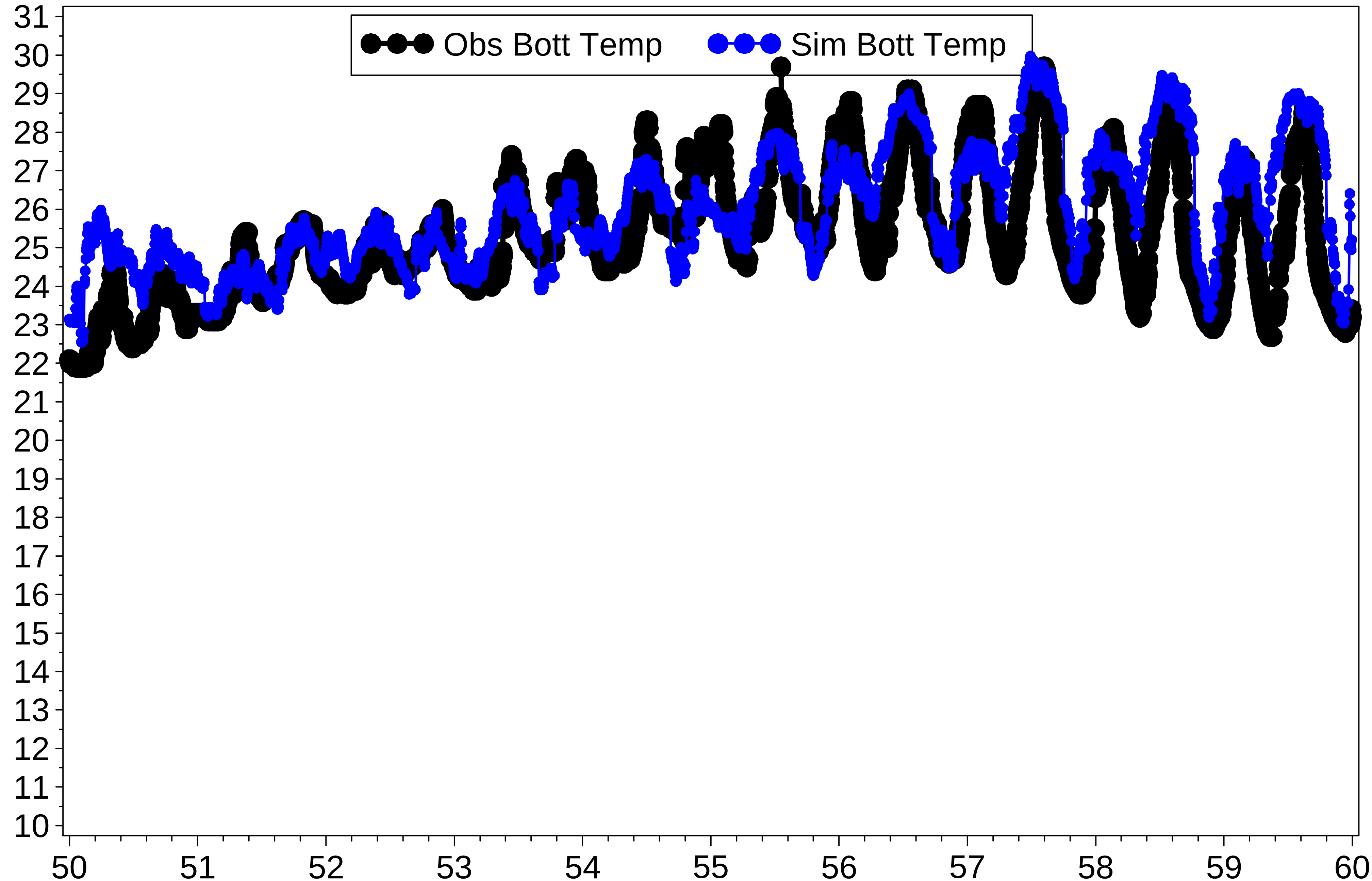
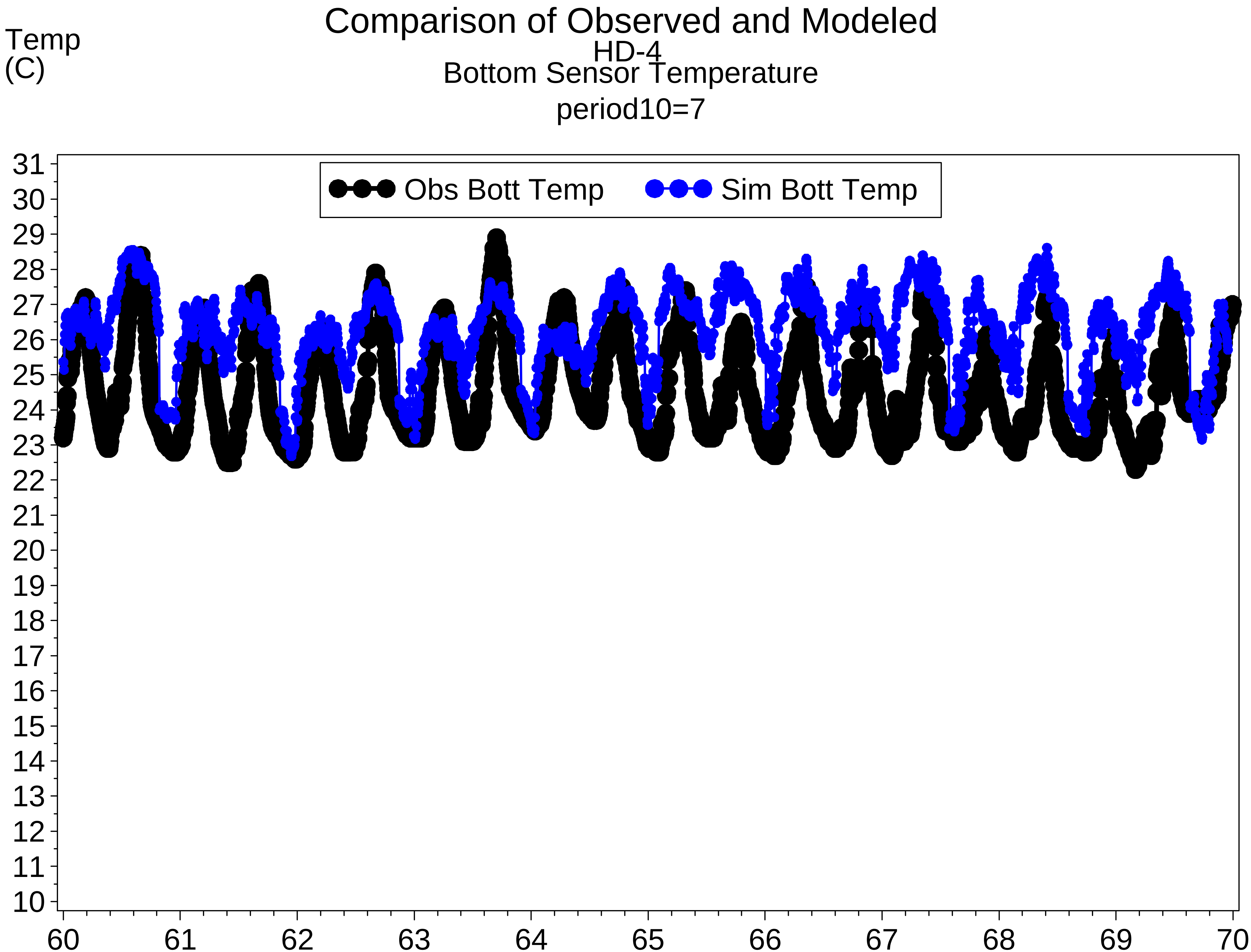
43
44
45
46
47
48
49
50

Comparison of Observed and Modeled
HD-4
Bottom Sensor Temperature
period10=6





Comparison of Observed and Modeled
HD-4
Bottom Sensor Temperature
period10=7
Temp
(C)
Obs Bott Temp
Sim Bott Temp
31
30
29
28
27
26
25
24
23
22
21
20
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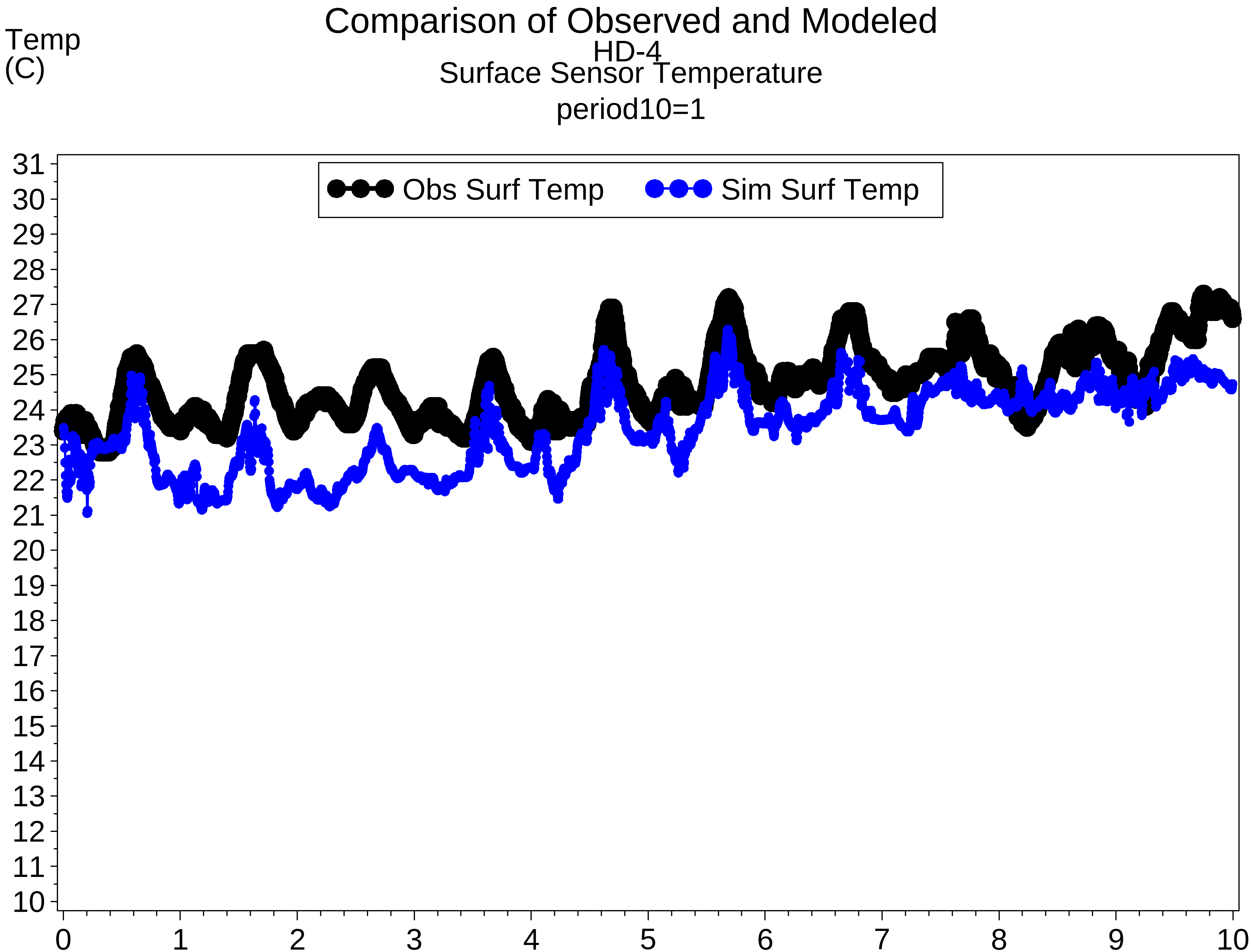

Comparison of Observed and Modeled
HD-4
Surface Sensor Temperature
period10=1
Temp
(C)
Obs Surf Temp
Sim Surf Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
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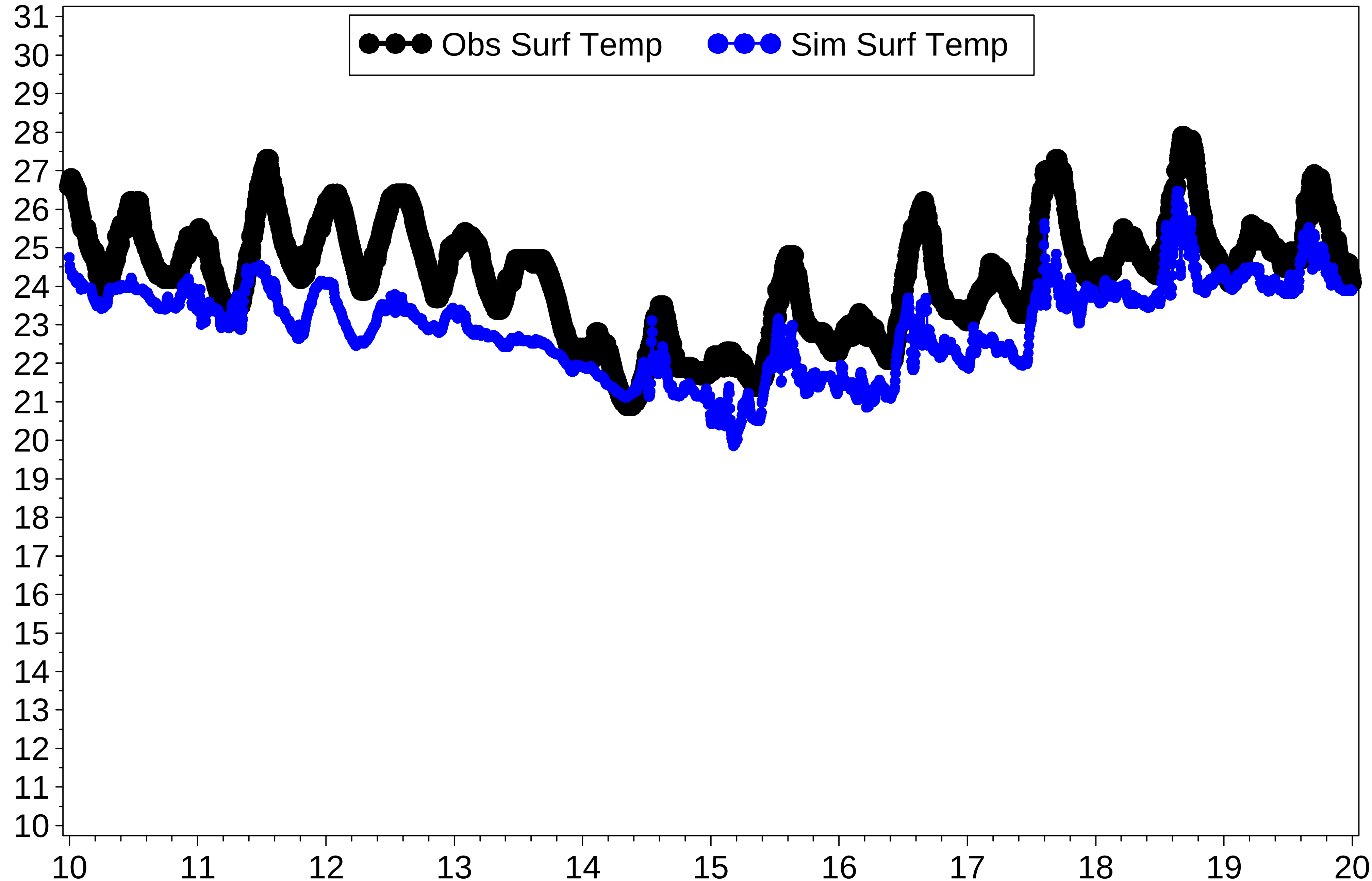
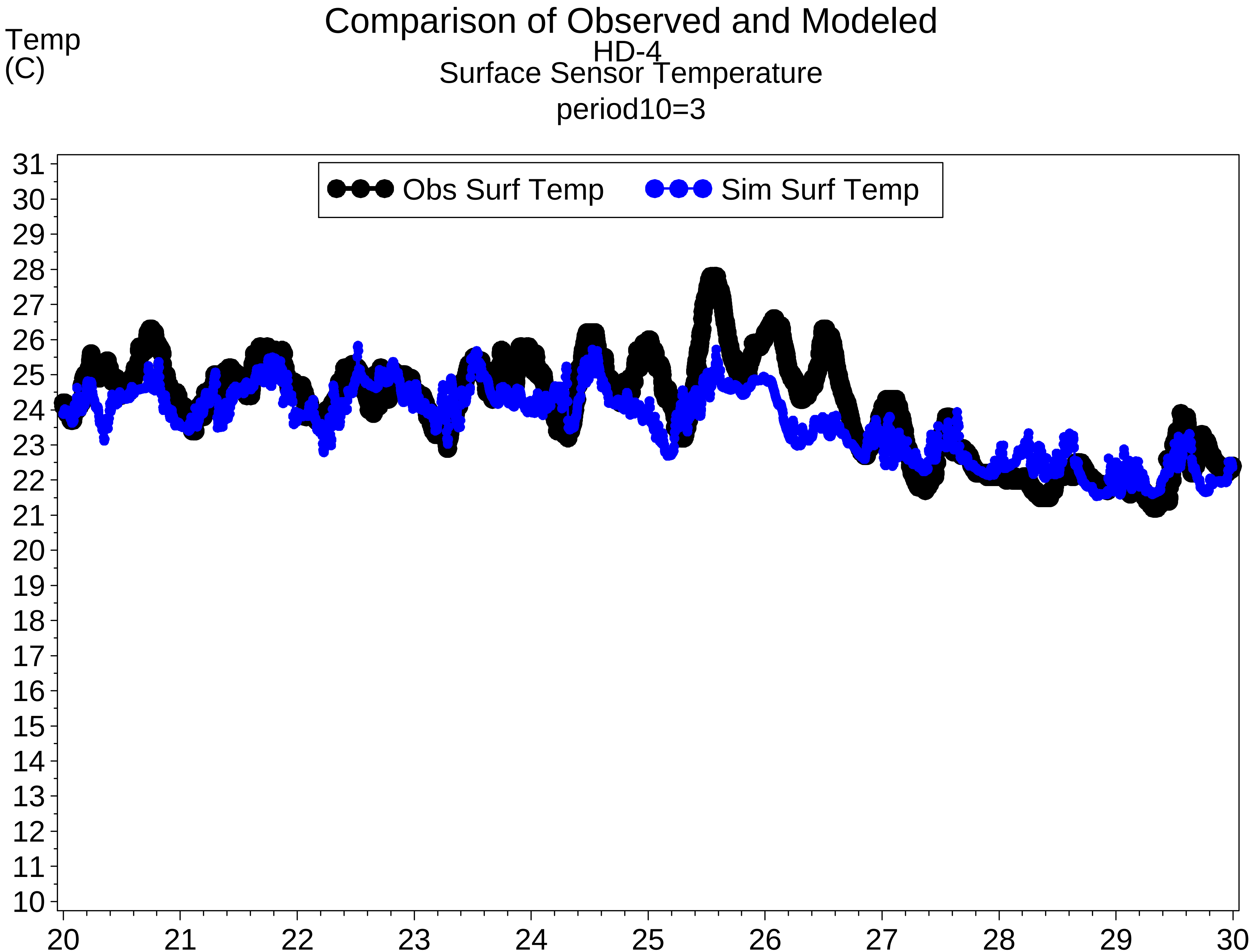
10

Comparison of Observed and Modeled
HD-4
Surface Sensor Temperature
period10=2




Comparison of Observed and Modeled
HD-4
Surface Sensor Temperature
period10=3
Temp
(C)
Obs Surf Temp
Sim Surf Temp
31
30
29
28
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26
25
24
23
22
21
20
19
18
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16
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13
12
11
10
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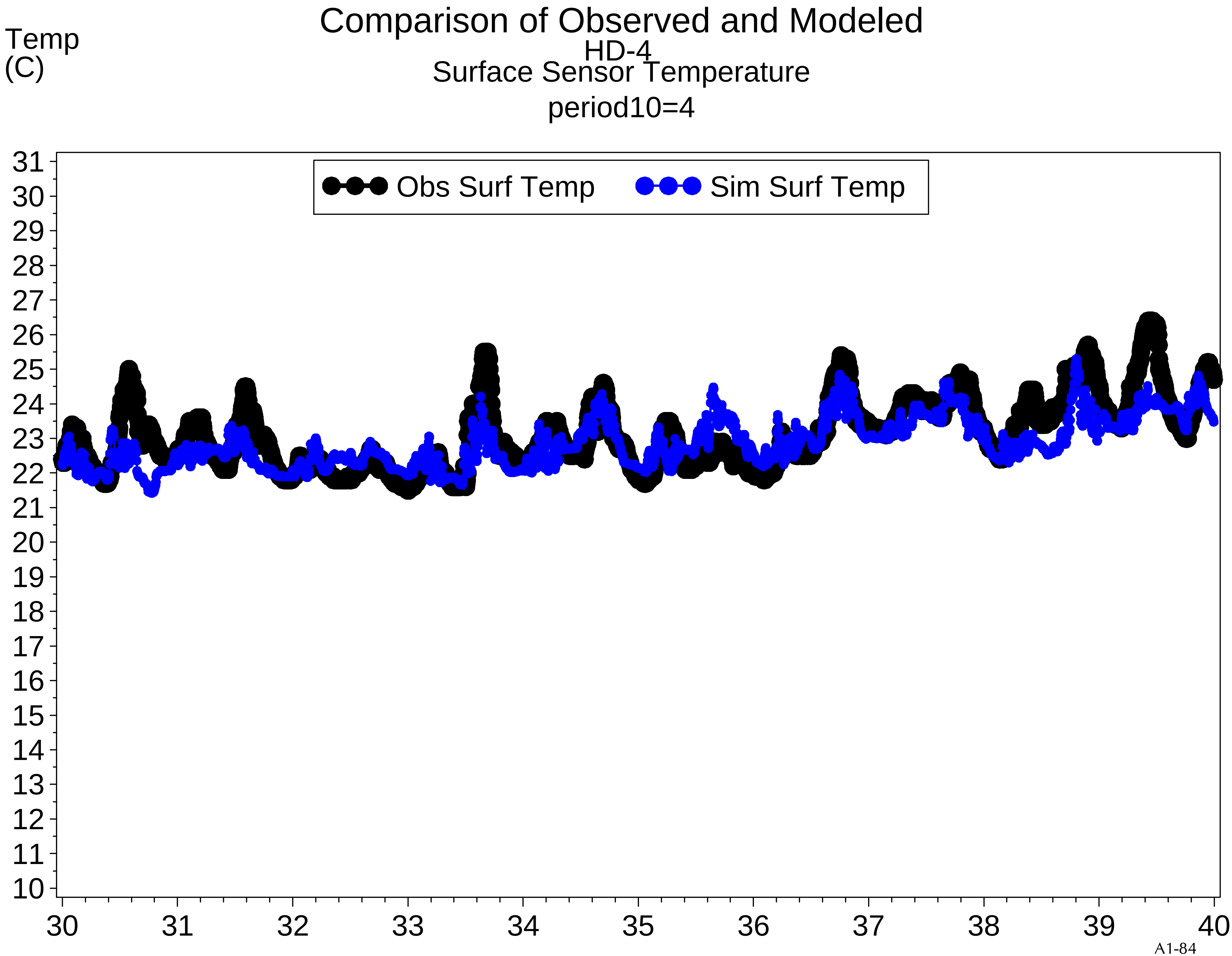

Comparison of Observed and Modeled
HD-4
Surface Sensor Temperature
period10=4
Temp
(C)
Obs Surf Temp
Sim Surf Temp
31
30
29
28
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26
25
24
23
22
21
20
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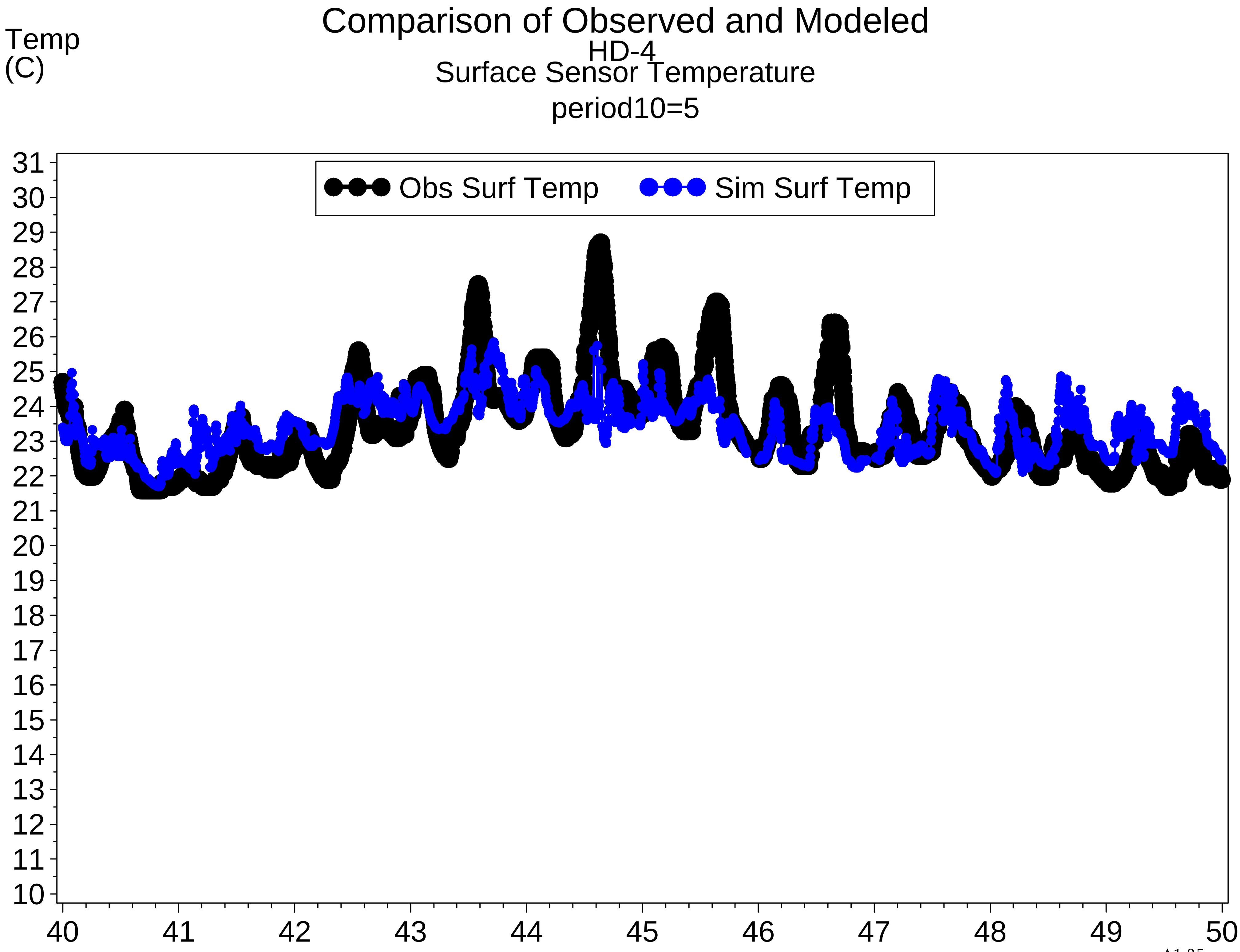
Temp
(C)
Comparison of Observed and Modeled
HD-4
Surface Sensor Temperature
period10=5
Obs Surf Temp
Sim Surf Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
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48
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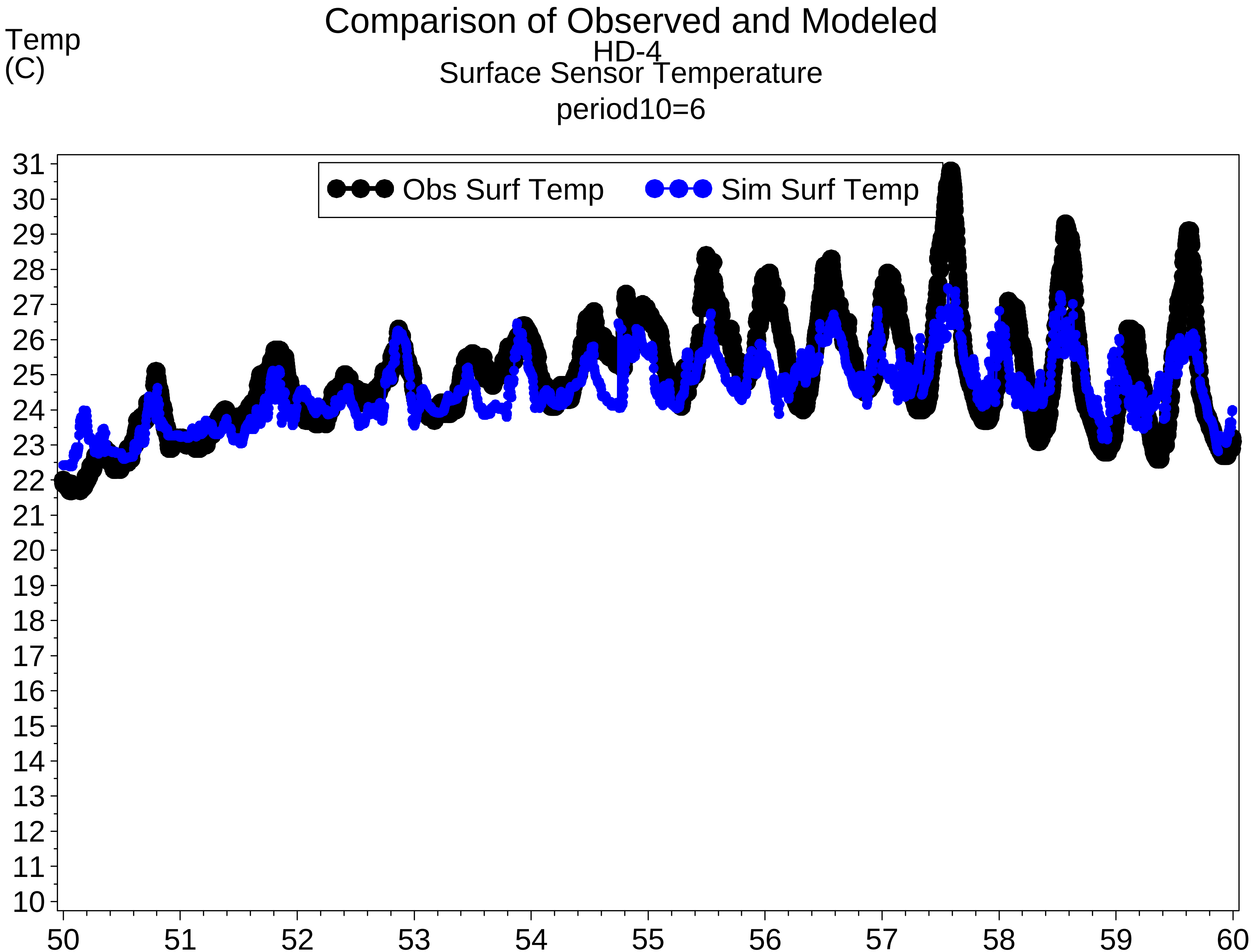
50



Comparison of Observed and Modeled
HD-4
Surface Sensor Temperature
period10=6
Temp
(C)
Obs Surf Temp
Sim Surf Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
50
51
52
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57
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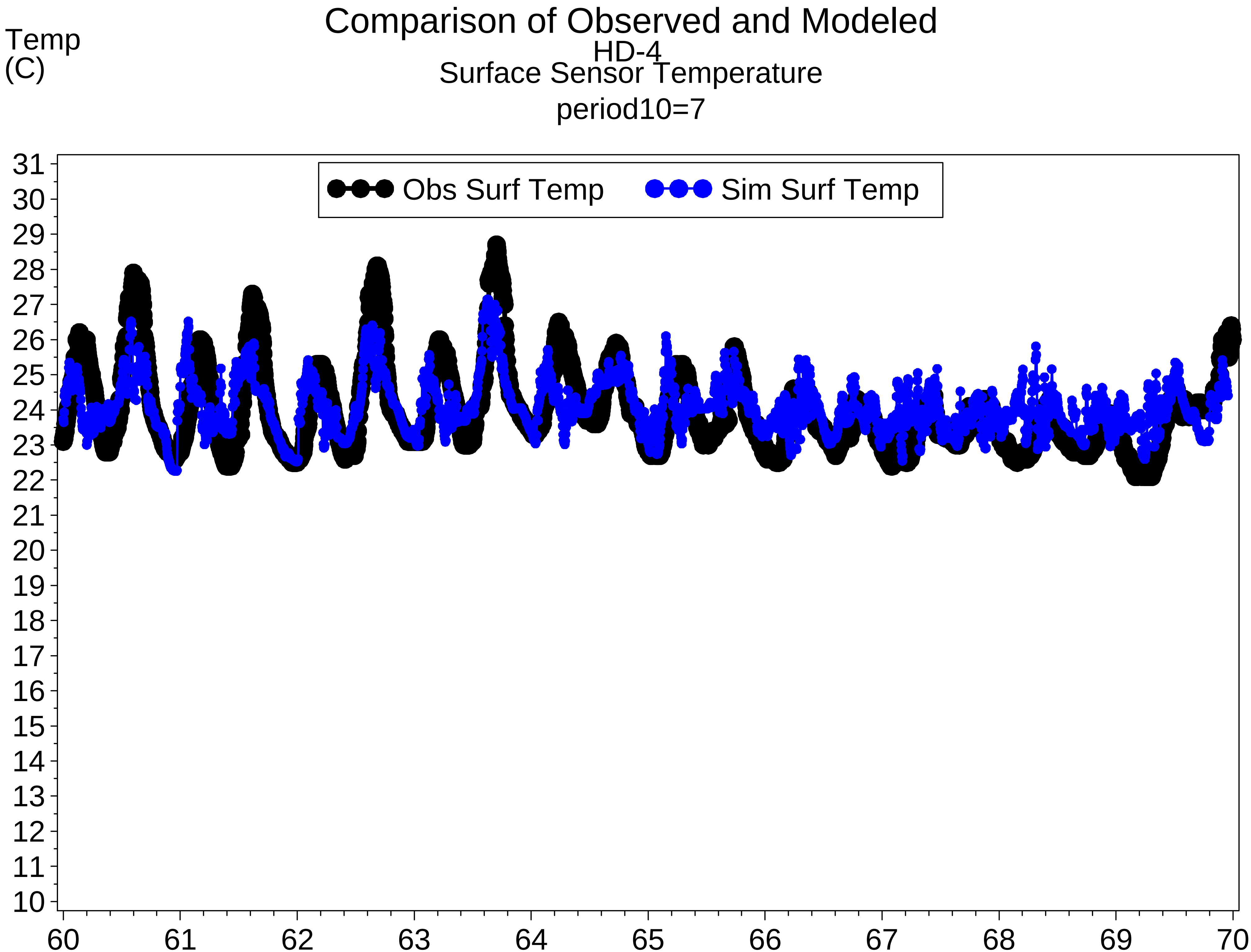
60


Temp
(C)
Comparison of Observed and Modeled
HD-4
Surface Sensor Temperature
period10=7
Obs Surf Temp
Sim Surf Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
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14
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60
61
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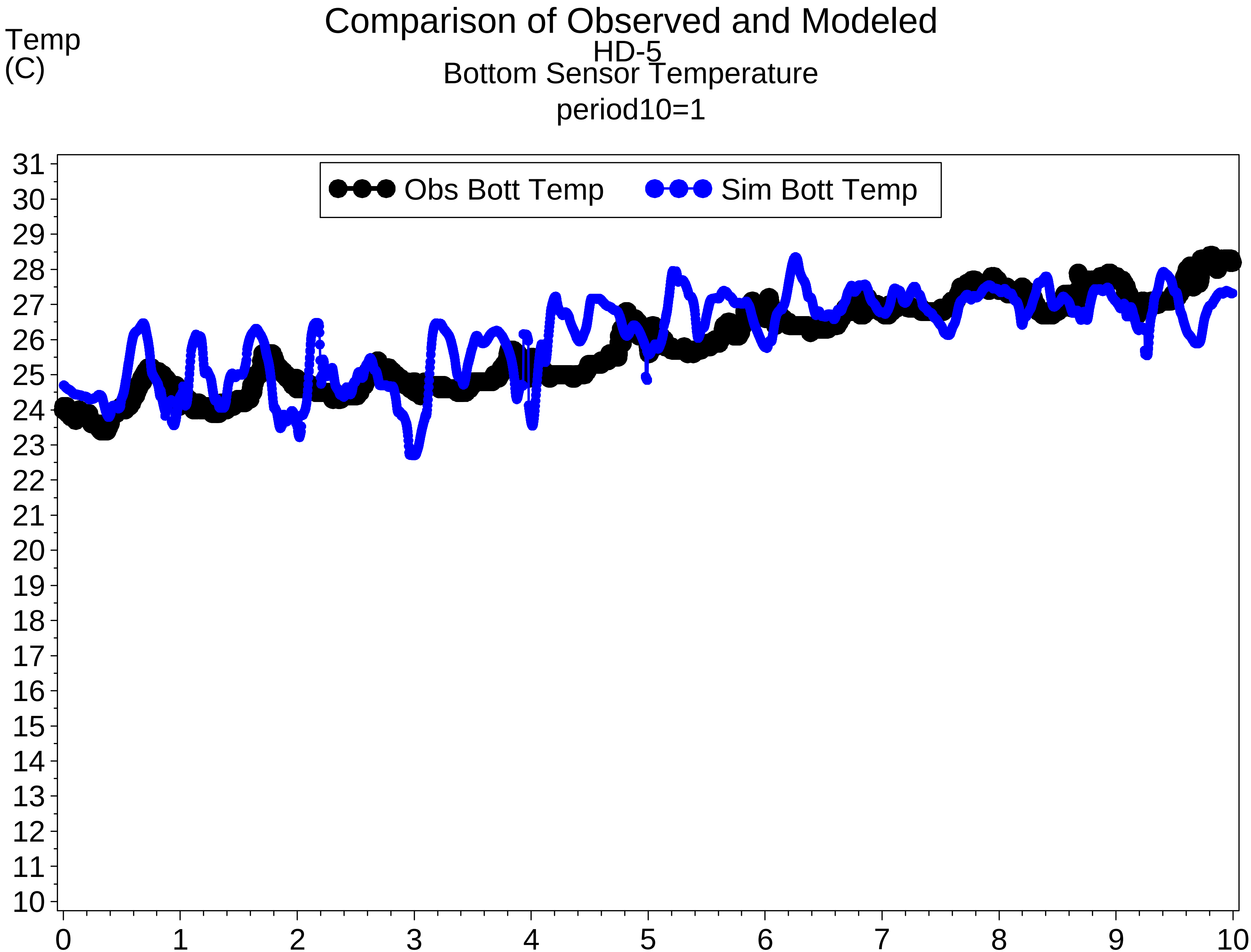
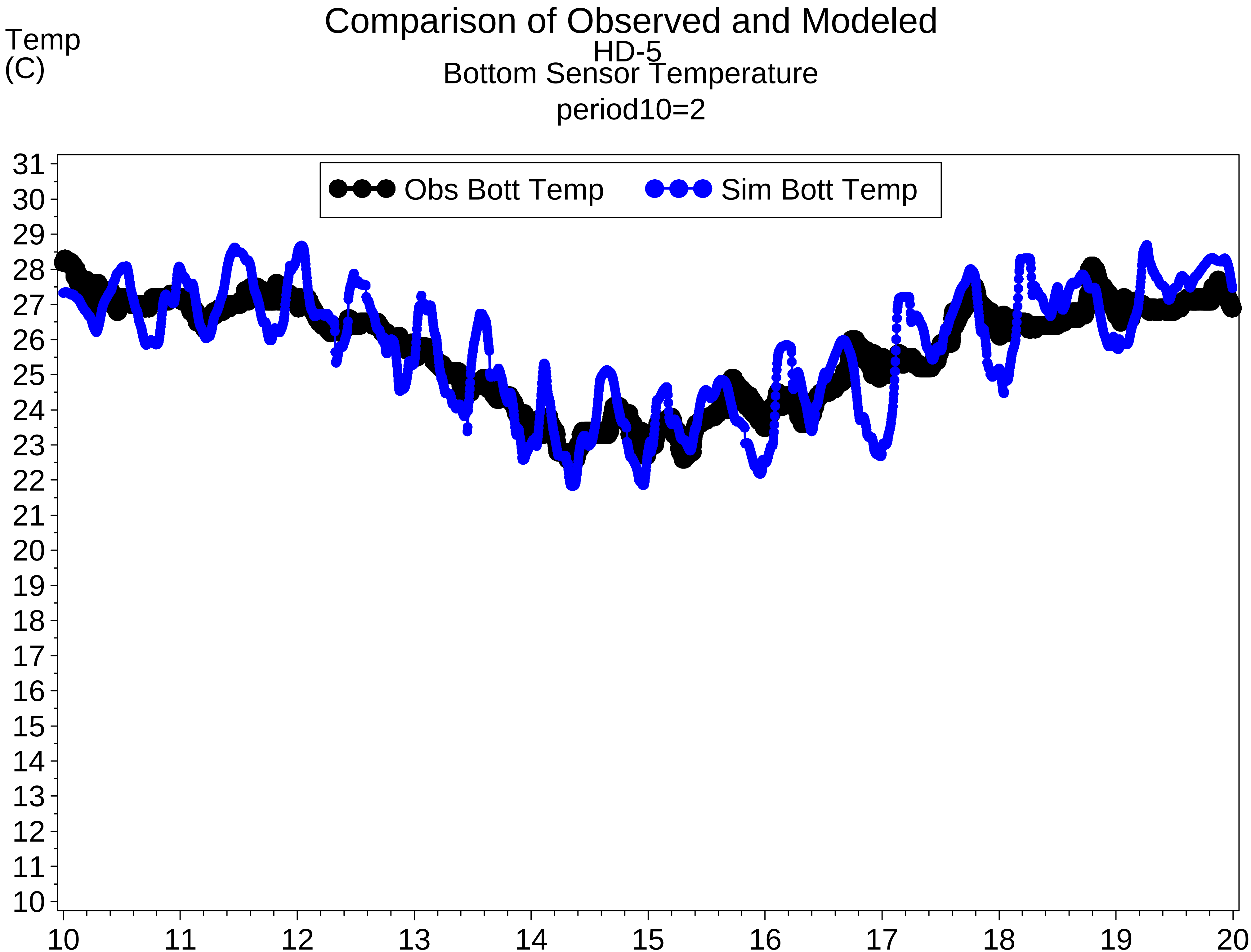
69
70



Comparison of Observed and Modeled
HD-5
Bottom Sensor Temperature
period10=1
Temp
(C)
Obs Bott Temp
Sim Bott Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
0
1
2
3
4
5
6
7
8
9
10

A1-88



Comparison of Observed and Modeled
HD-5
Bottom Sensor Temperature
period10=2
Temp
(C)
Obs Bott Temp
Sim Bott Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
10
11
12
13
14
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16
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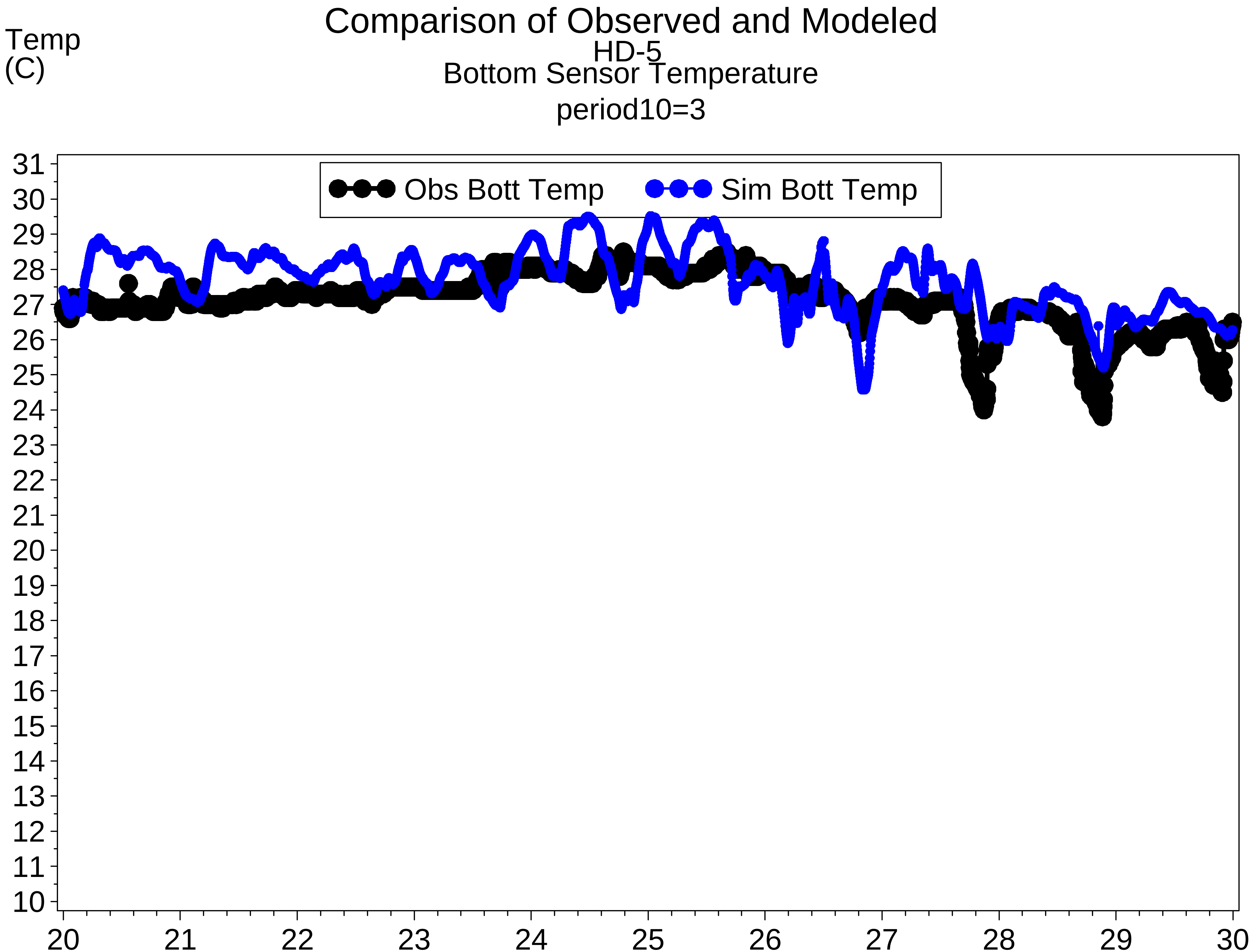
19
20



Comparison of Observed and Modeled
HD-5
Bottom Sensor Temperature
period10=3
Temp
(C)
Obs Bott Temp
Sim Bott Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
20
21
22
23
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25
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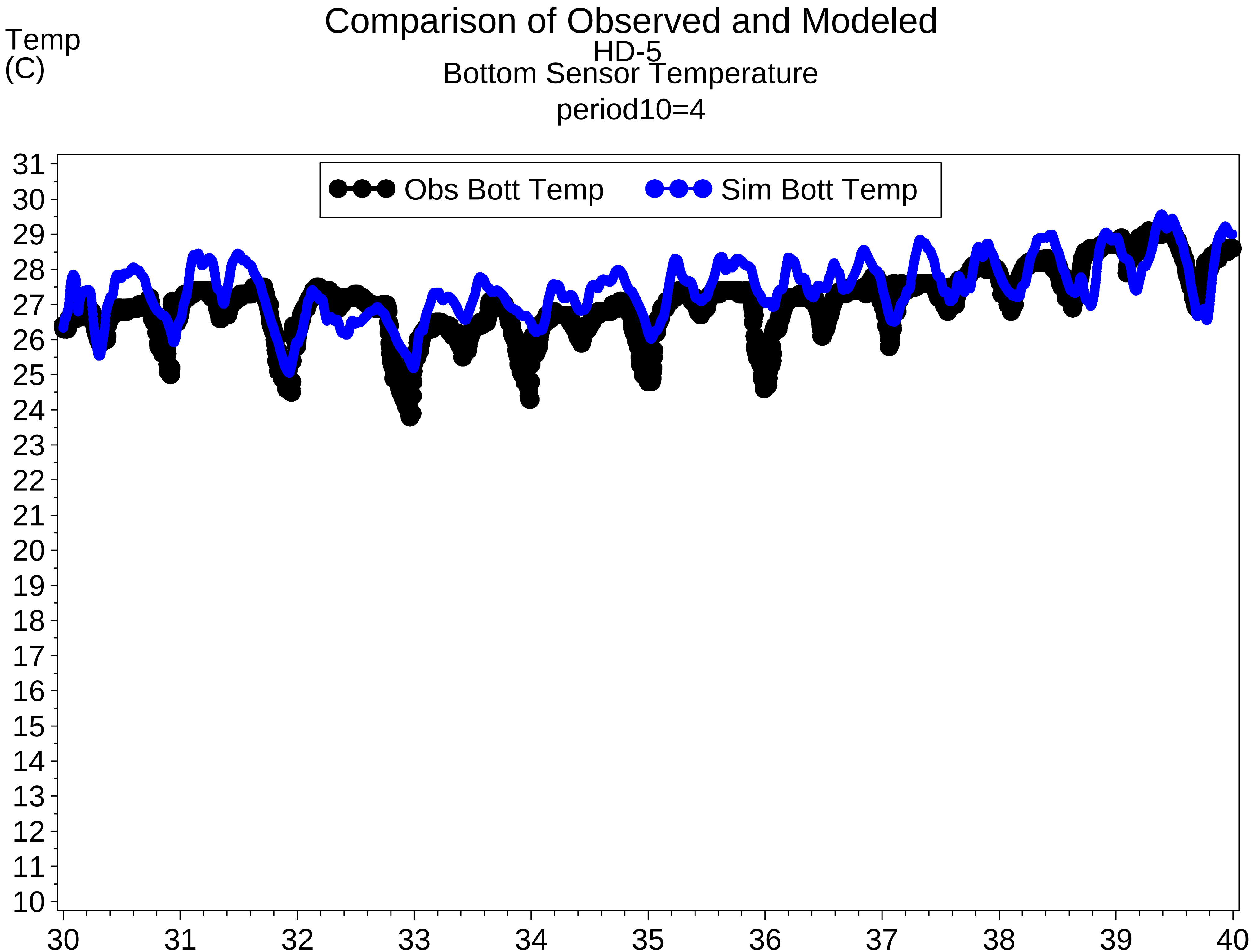
29
30

A1-90



Comparison of Observed and Modeled
HD-5
Bottom Sensor Temperature
period10=4
Temp
(C)
Obs Bott Temp
Sim Bott Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
30
31
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33
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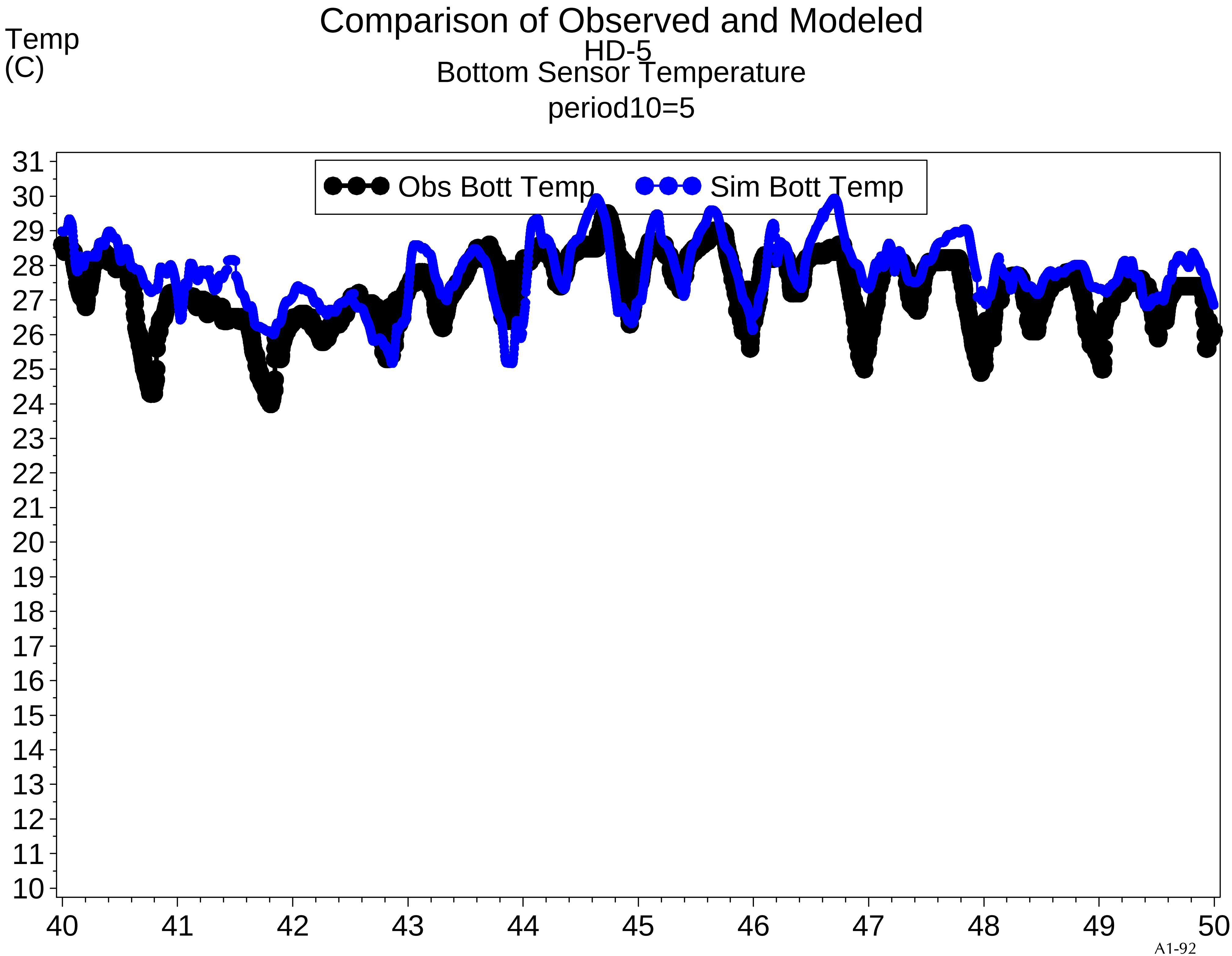

Comparison of Observed and Modeled
HD-5
Bottom Sensor Temperature
period10=5
Temp
(C)
Obs Bott Temp
Sim Bott Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
40
41
42
43
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47
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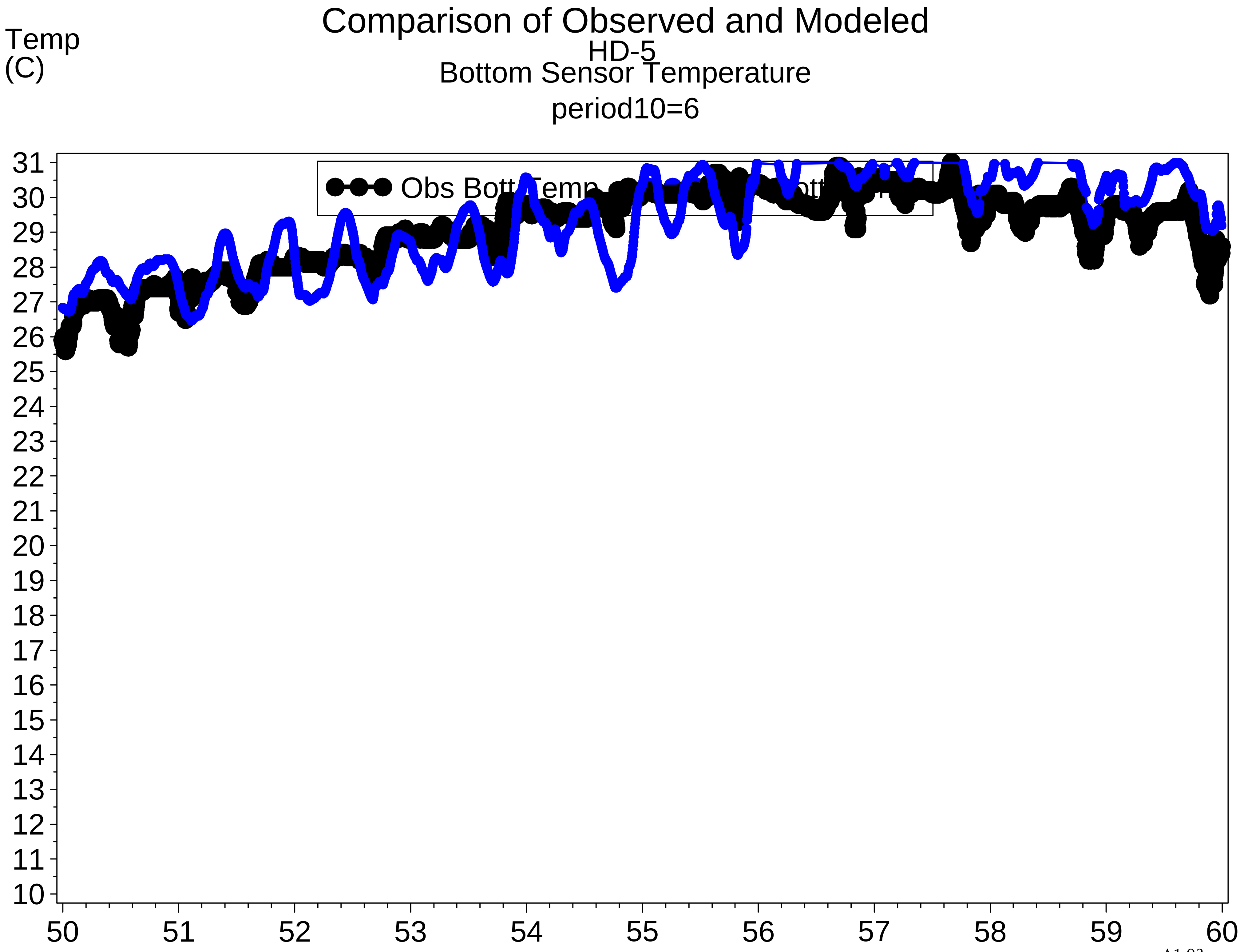

Comparison of Observed and Modeled
HD-5
Bottom Sensor Temperature
period10=6
Temp
(C)
Obs Bott Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
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12
11
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58
59
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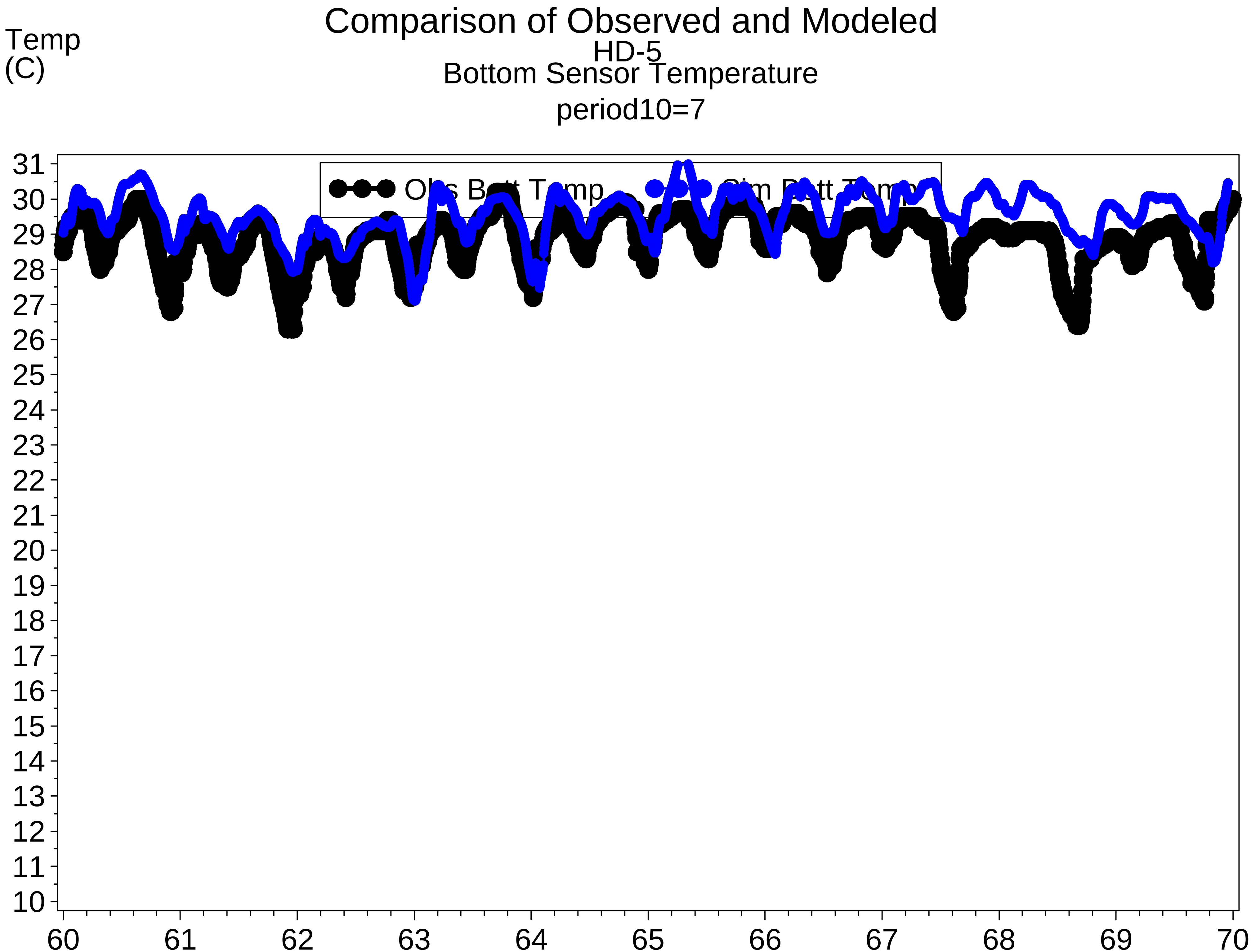
A1-93


Comparison of Observed and Modeled
HD-5
Bottom Sensor Temperature
period10=7
Temp
(C)
Obs Bott Temp
Sim Bott Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
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66
67
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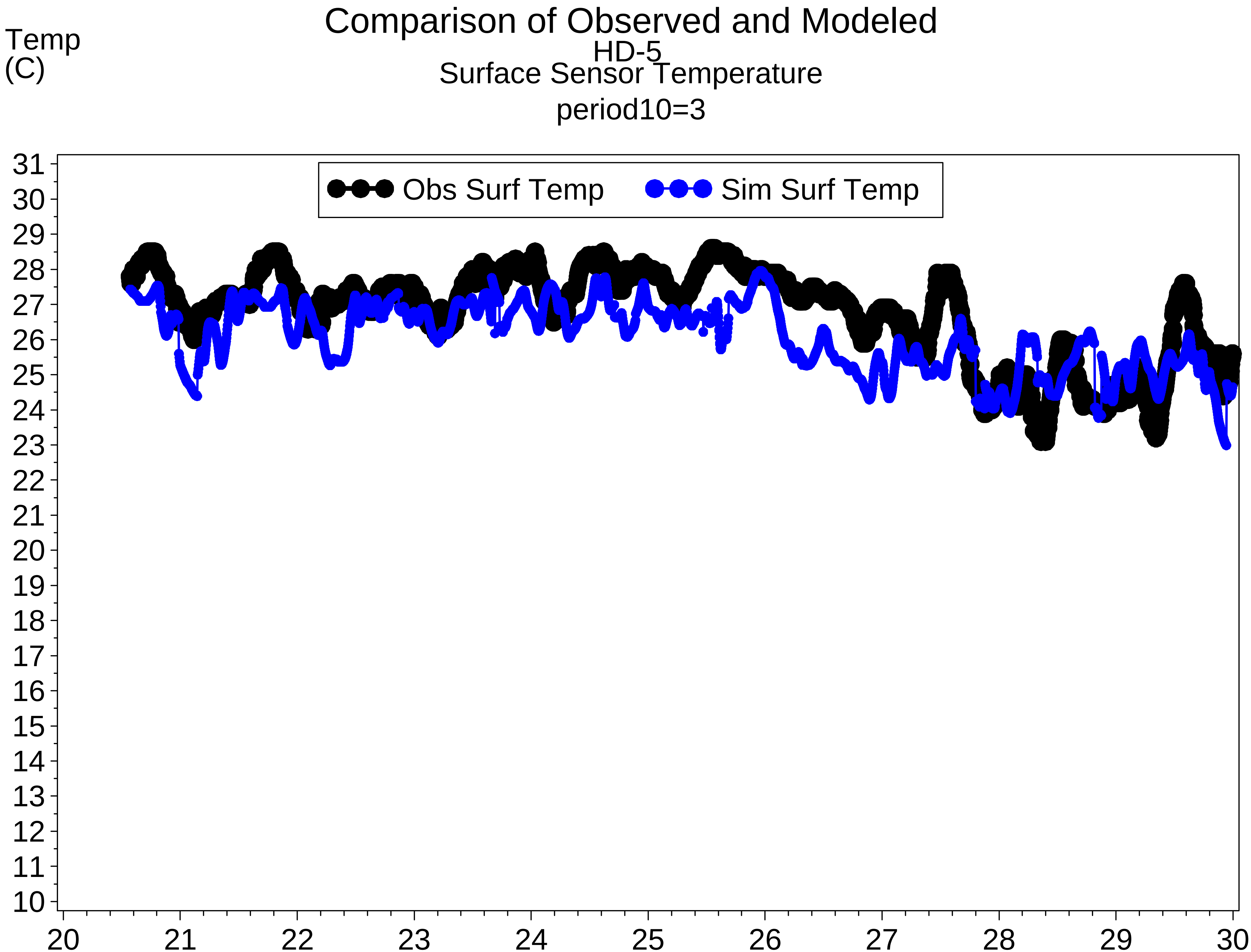
Comparison of Observed and Modeled
HD-5
Surface Sensor Temperature
period10=3
Temp
(C)
Obs Surf Temp
Sim Surf Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
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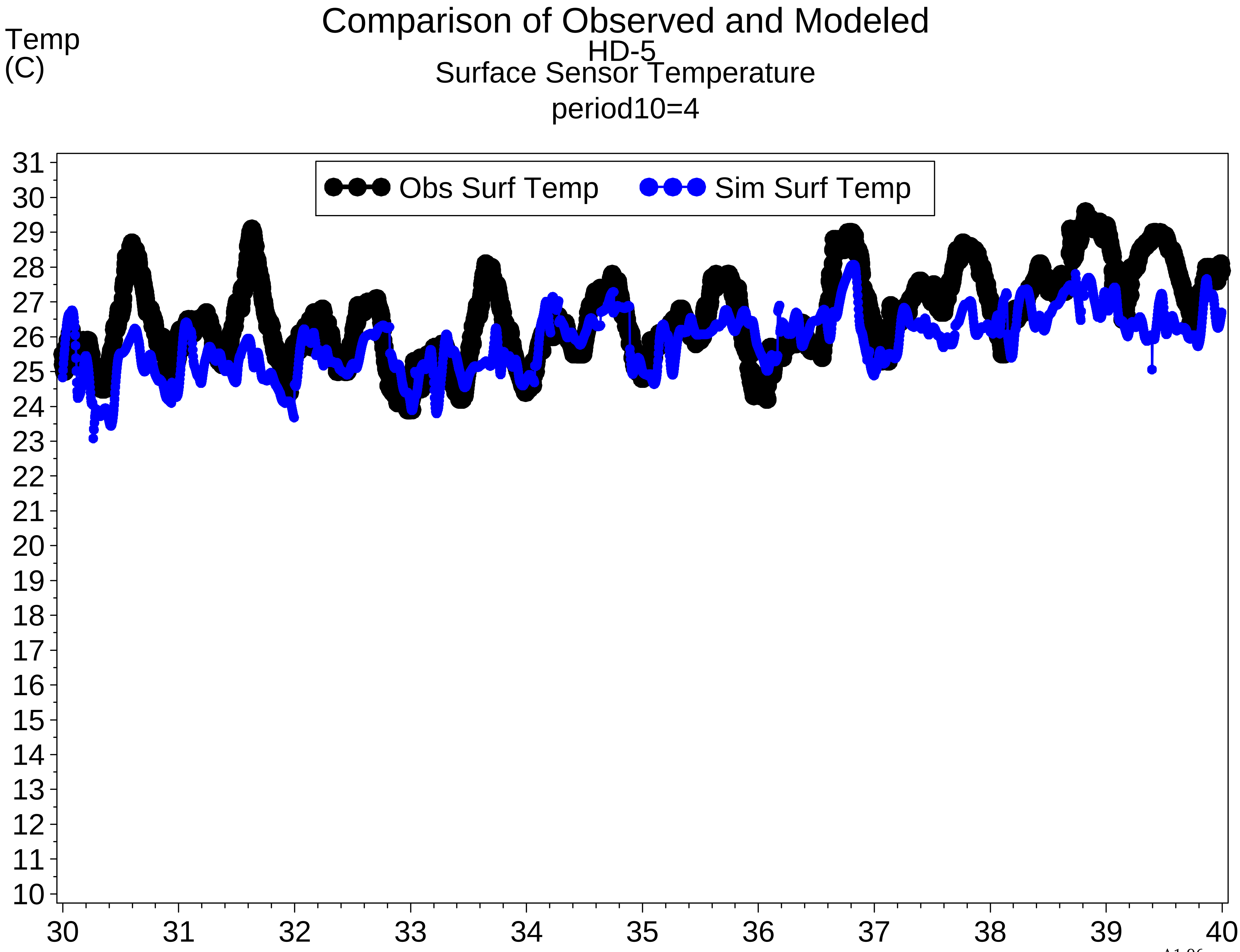
29
30



Temp
(C)
Comparison of Observed and Modeled
HD-5
Surface Sensor Temperature
period10=4
Obs Surf Temp
Sim Surf Temp
31
30
29
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27
26
25
24
23
22
21
20
19
18
17
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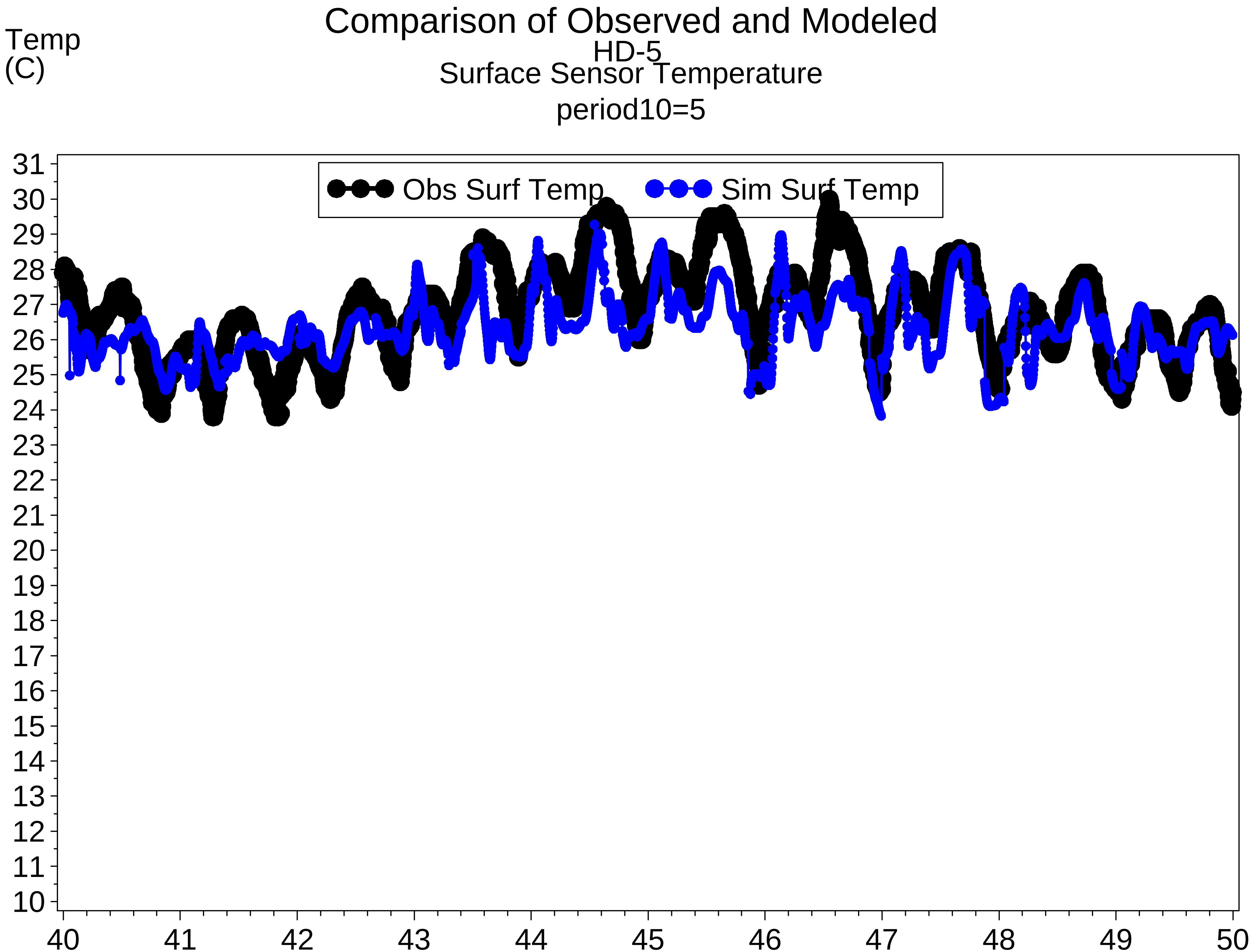
Comparison of Observed and Modeled
HD-5
Surface Sensor Temperature
period10=5
Temp
(C)
Obs Surf Temp
Sim Surf Temp
31
30
29
28
27
26
25
24
23
22
21
20
19
18
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16
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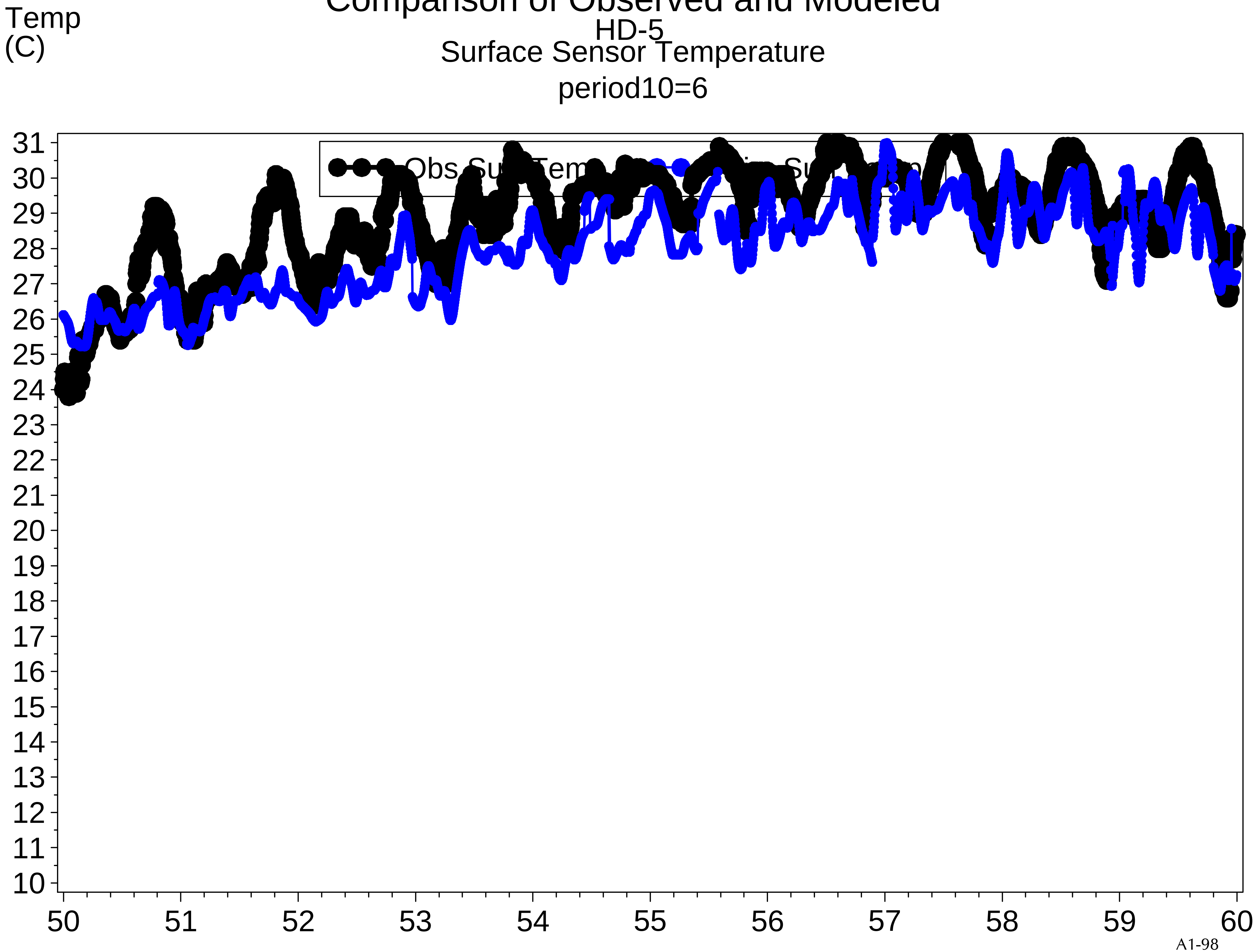
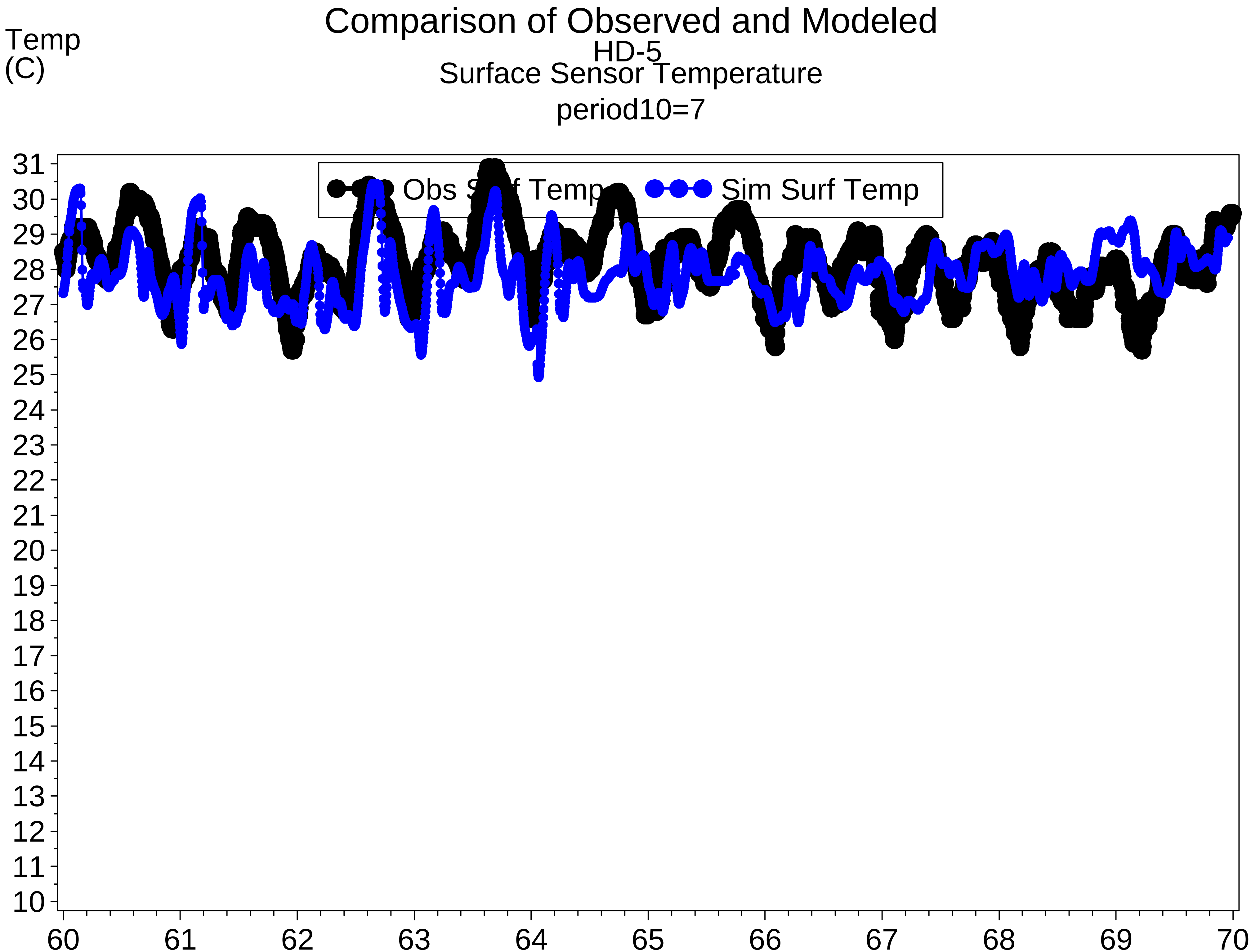
Comparison of Observed and Modeled

HD-5

Surface Sensor Temperature

period10=6





Comparison of Observed and Modeled
HD-5
Surface Sensor Temperature
period10=7
Temp
(C)
Obs Surf Temp
Sim Surf Temp
31
30
29
28
27
26
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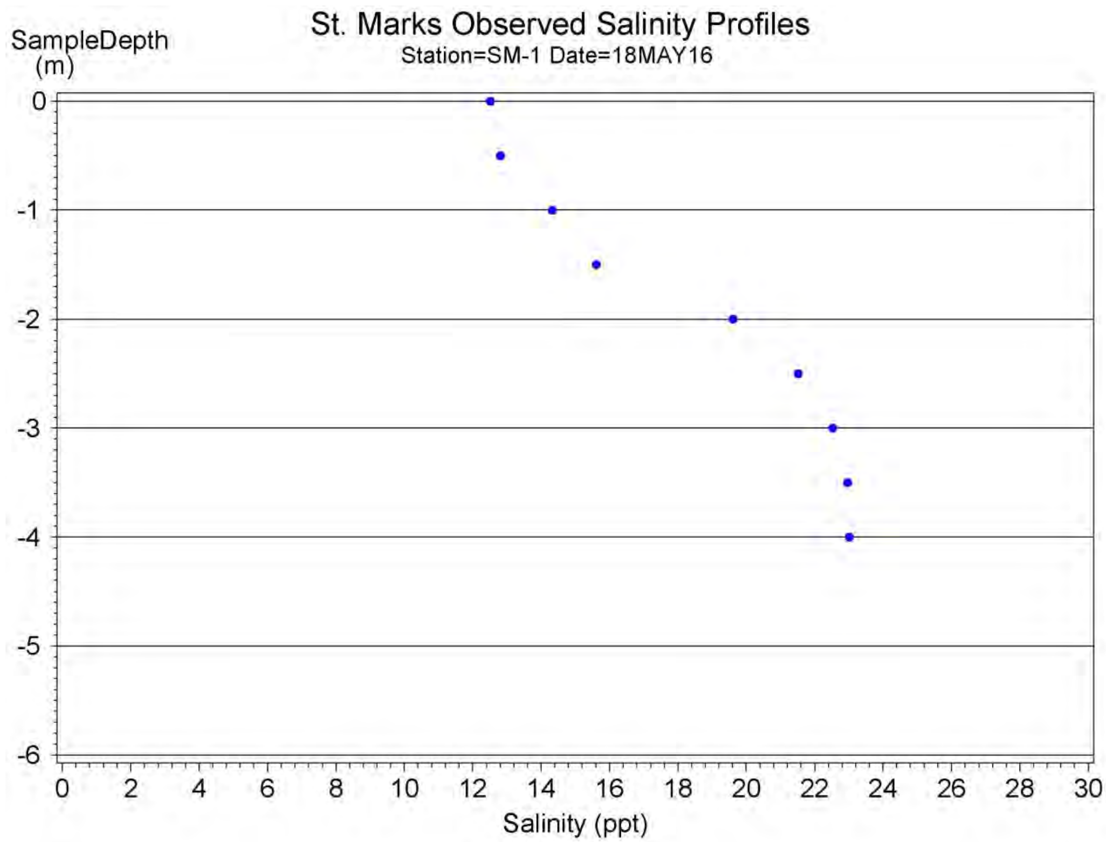
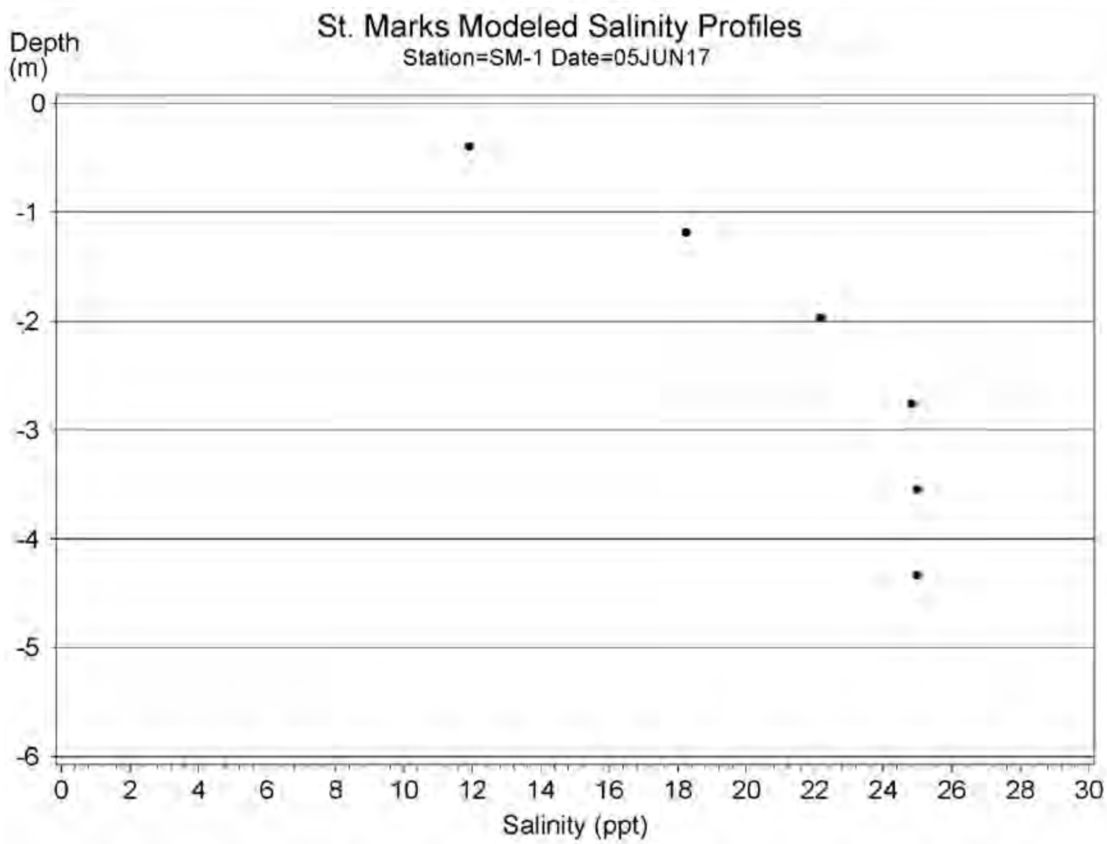
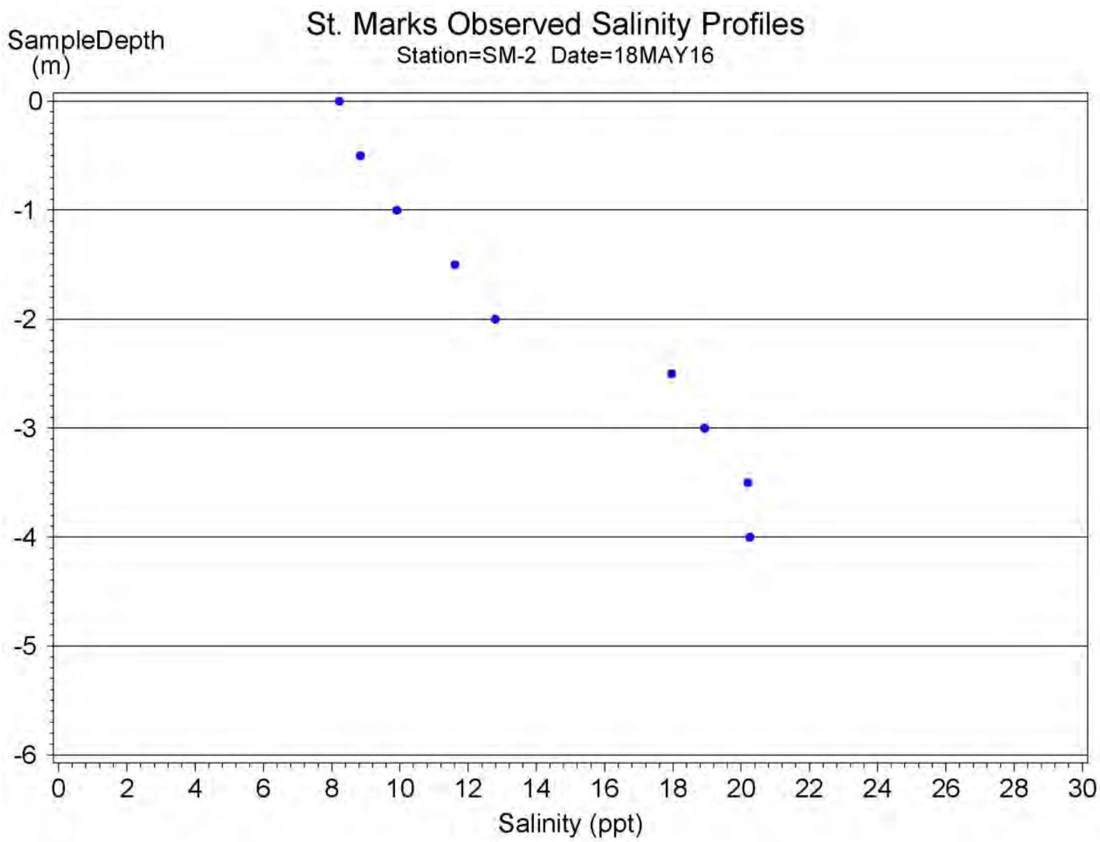
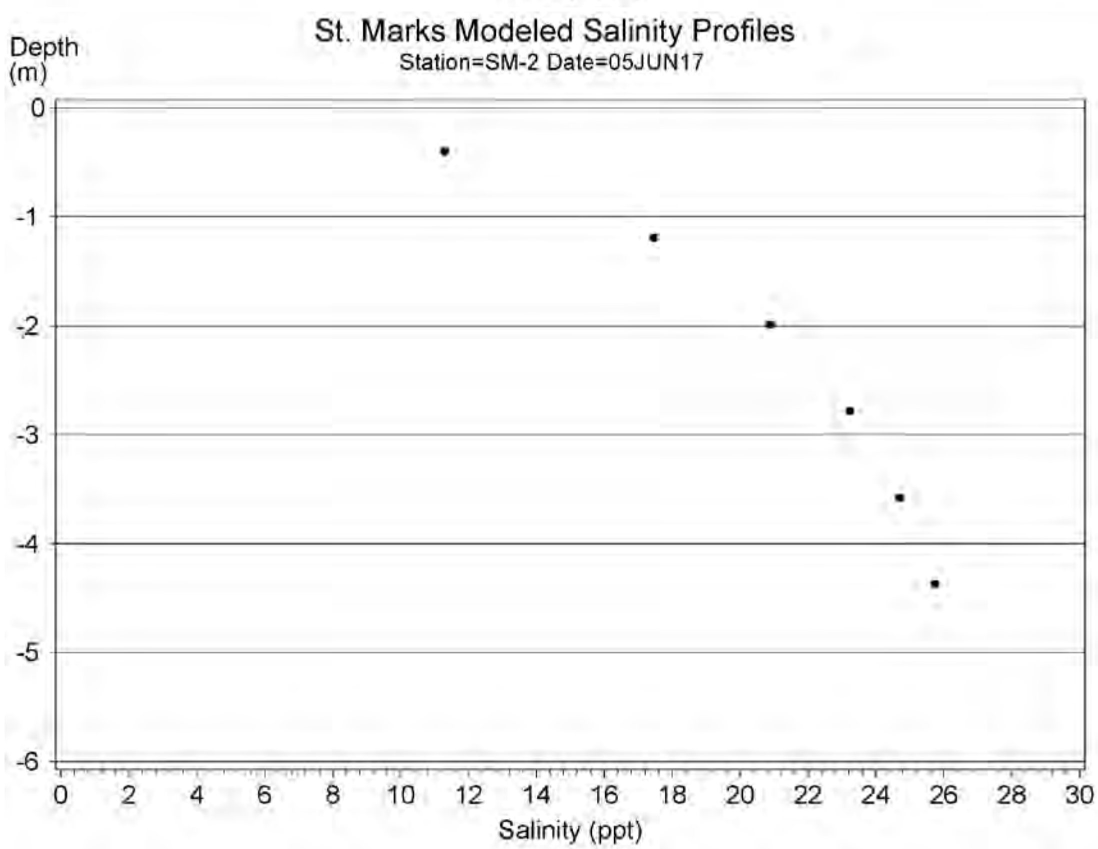
A1-99

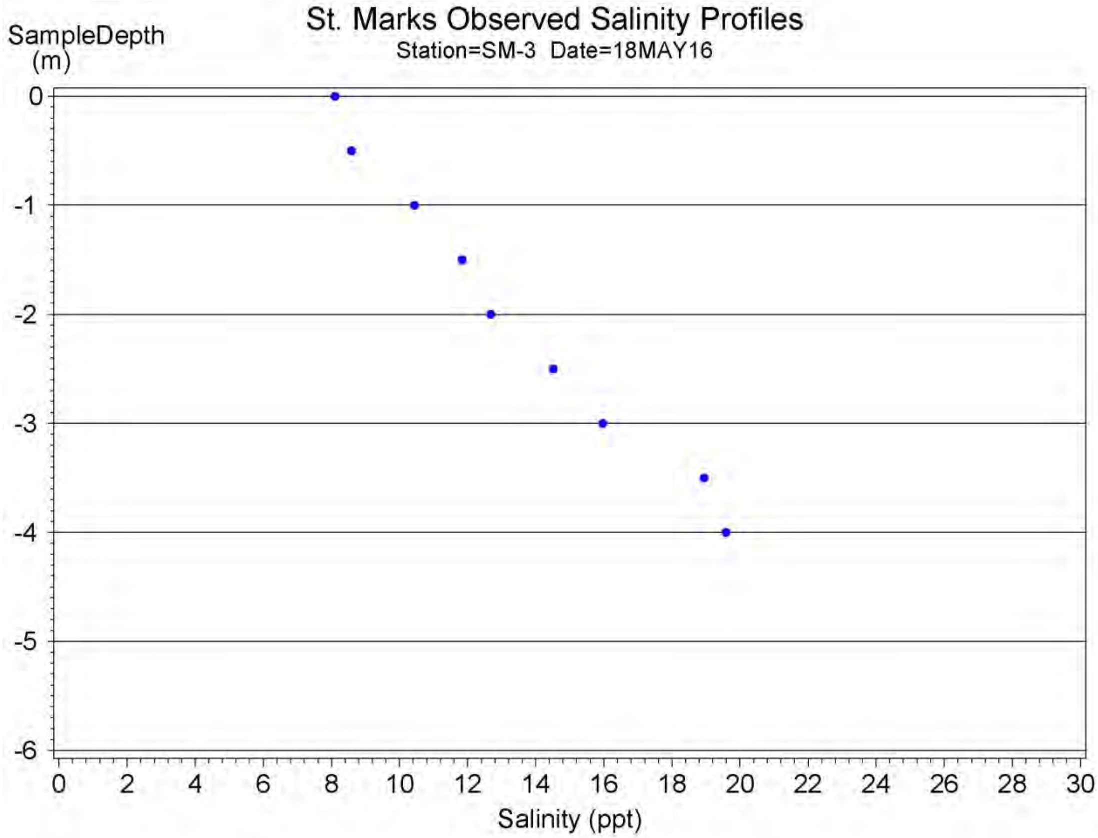
ATTACHMENT 2
COMPARISONS OF VERTICAL SALINITY:
OBSERVED PROFILE DATA
MAY 2016 - APRIL 2017
TO
SIMULATED PROFILE DATA
CALIBRATION PERIOD
DURING SIMILAR FLOW CONDITIONS

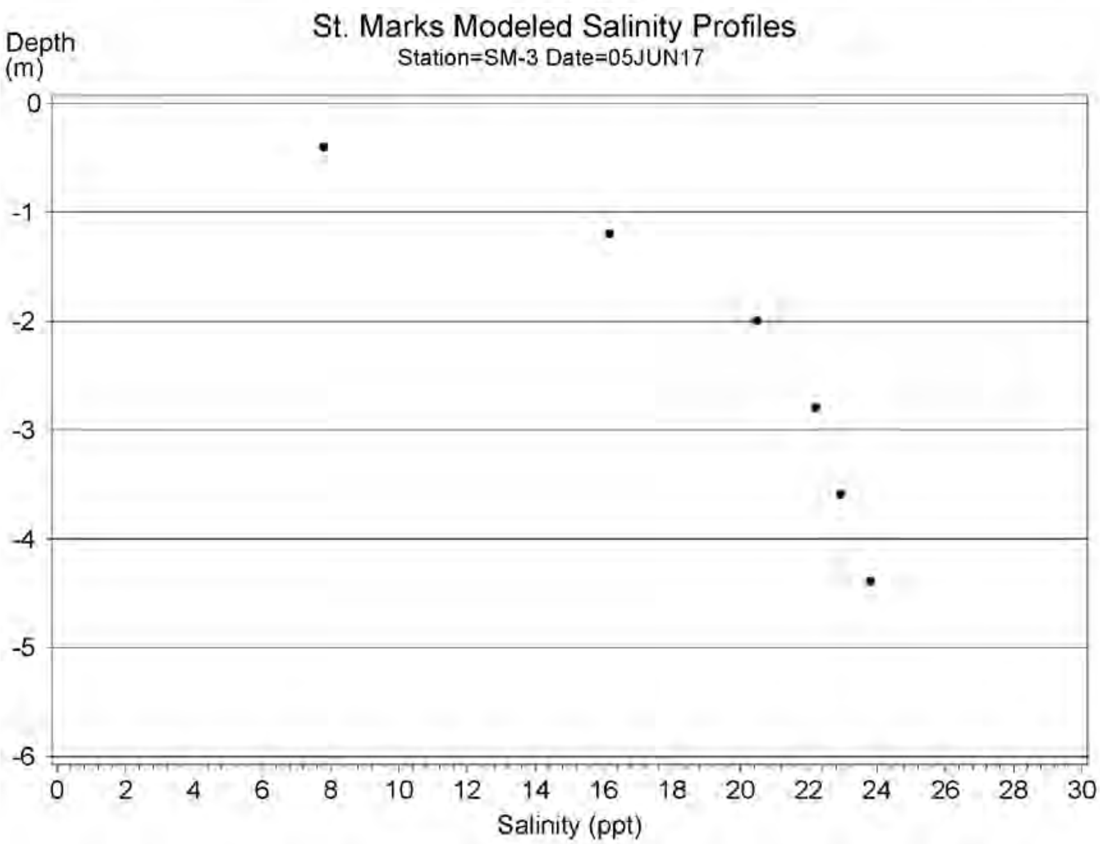

St. Marks Observed Salinity Profiles
Station=SM-1 Date=18MAY16
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

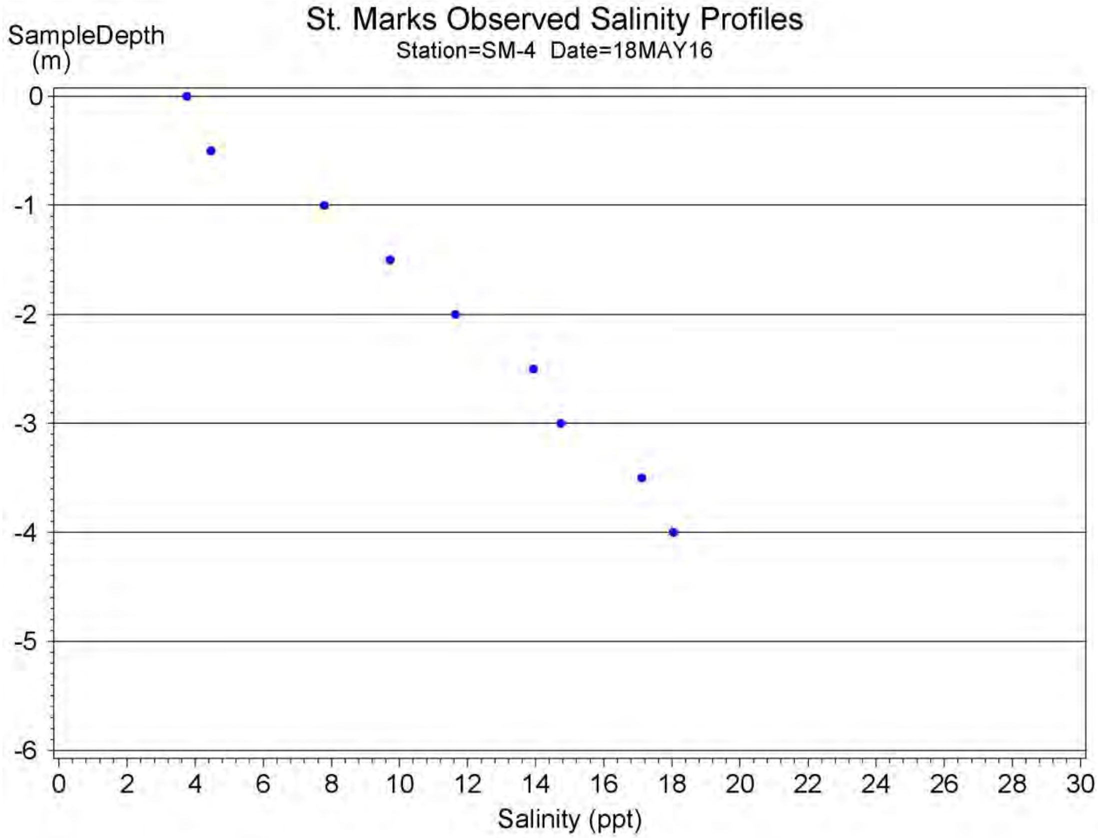

St. Marks Modeled Salinity Profiles
Station=SM-1 Date=05JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

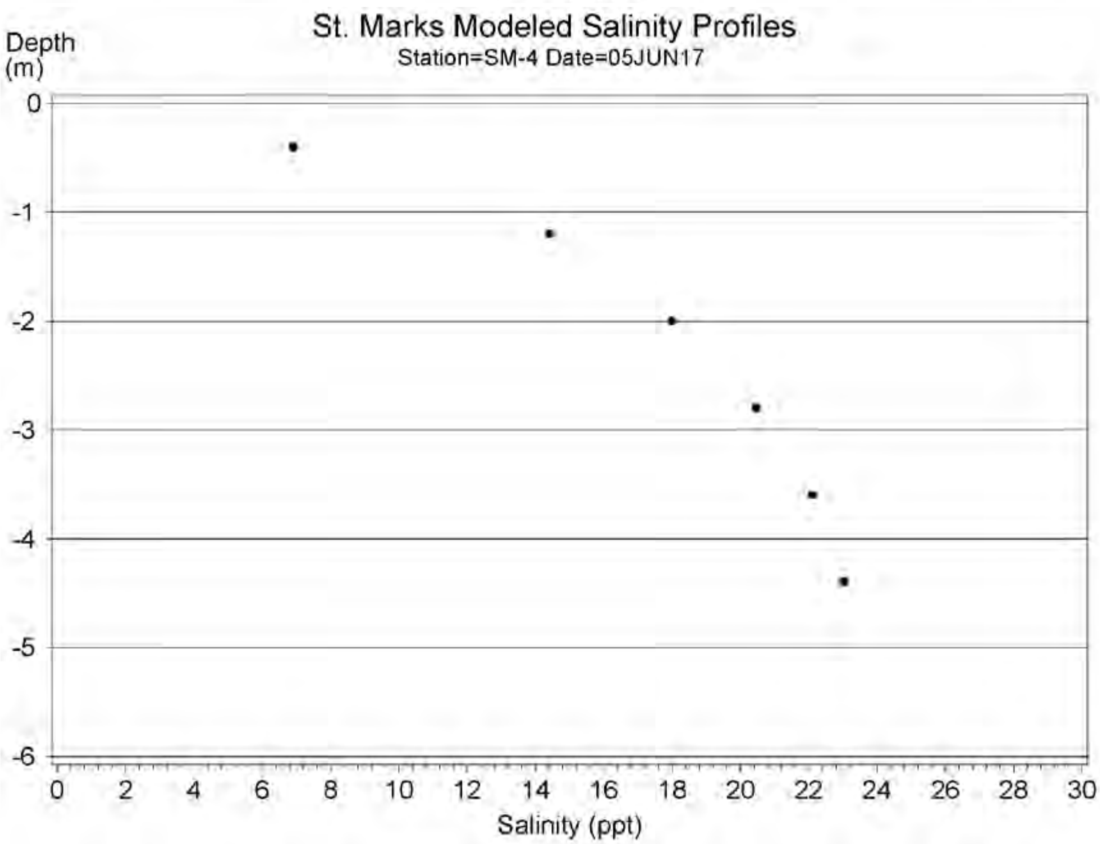

St. Marks Observed Salinity Profiles
Station=SM-2 Date=18MAY16
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

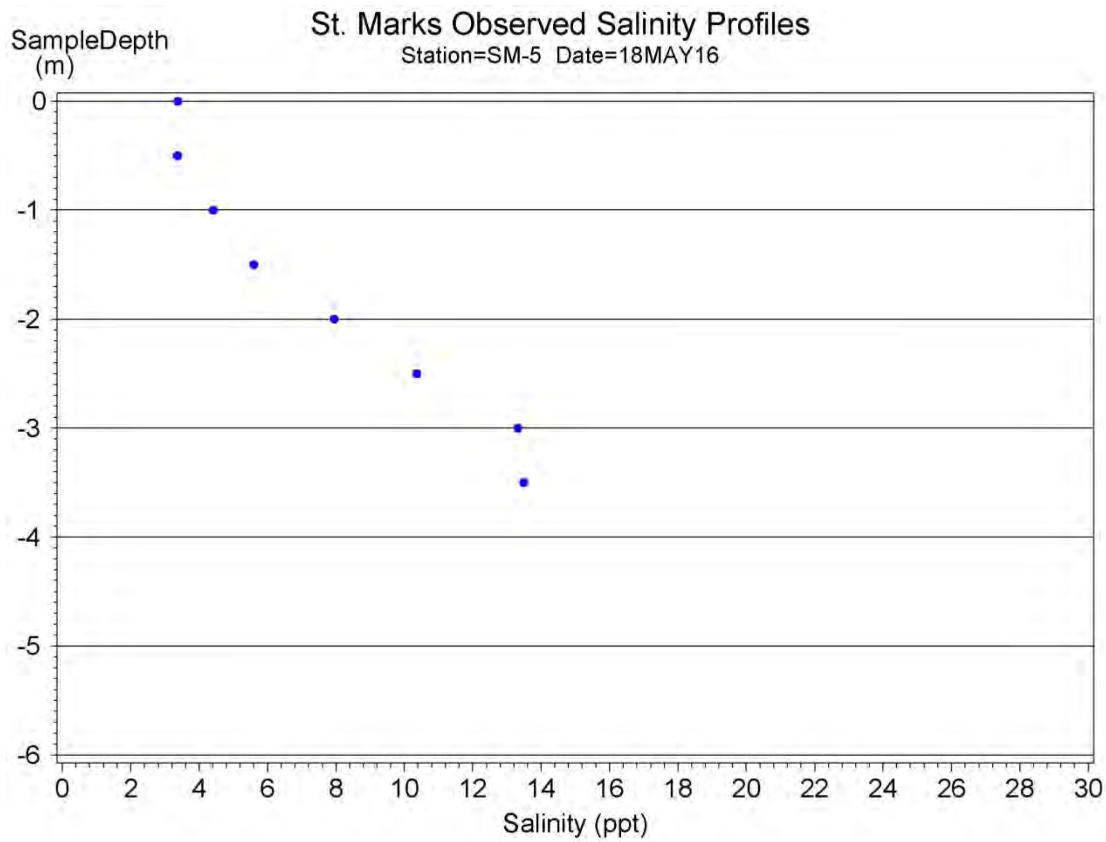

St. Marks Modeled Salinity Profiles
Station=SM-2 Date=05JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

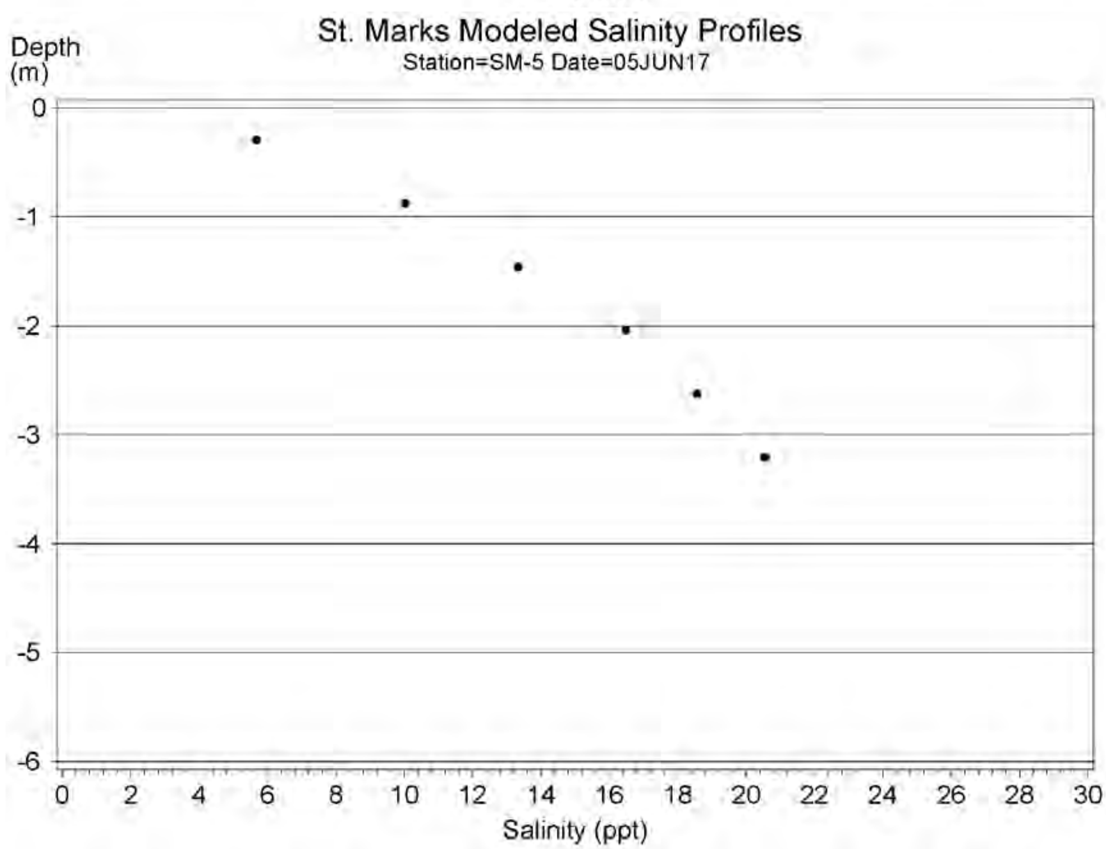

St. Marks Observed Salinity Profiles
Station=SM-3 Date=18MAY16
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

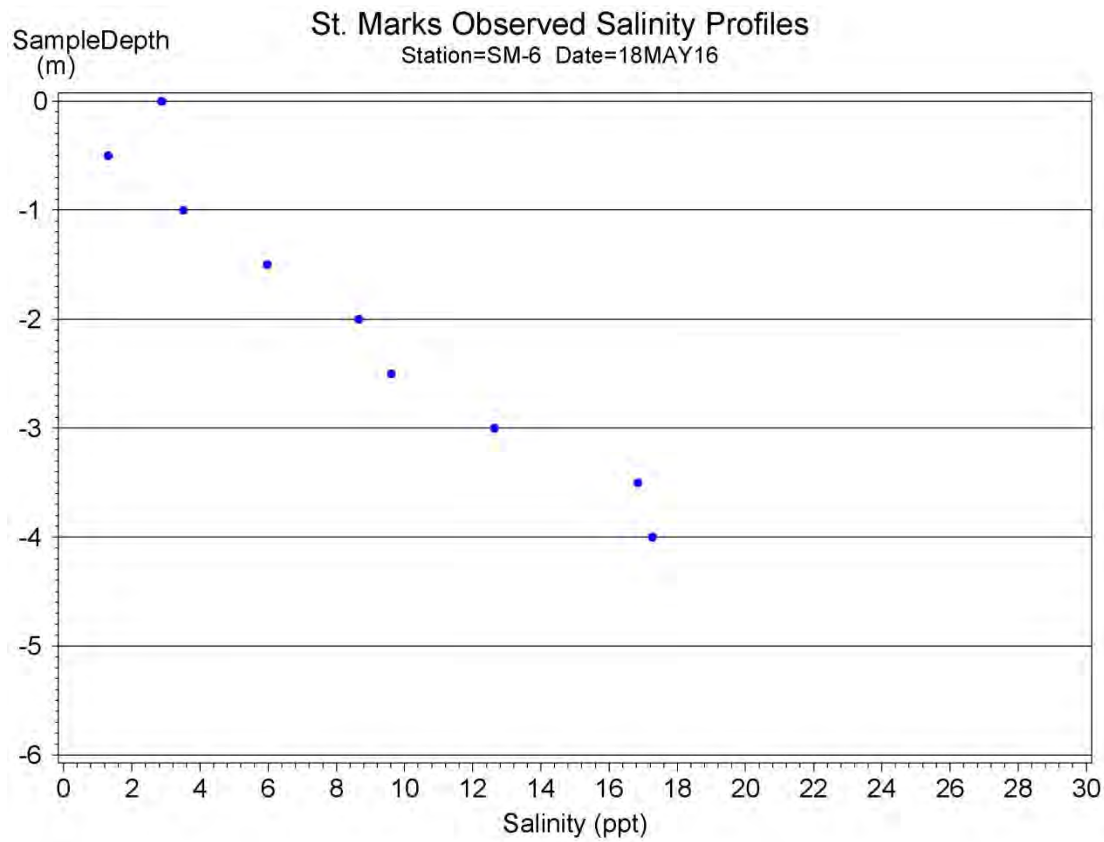

St. Marks Modeled Salinity Profiles
Station=SM-3 Date=05JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

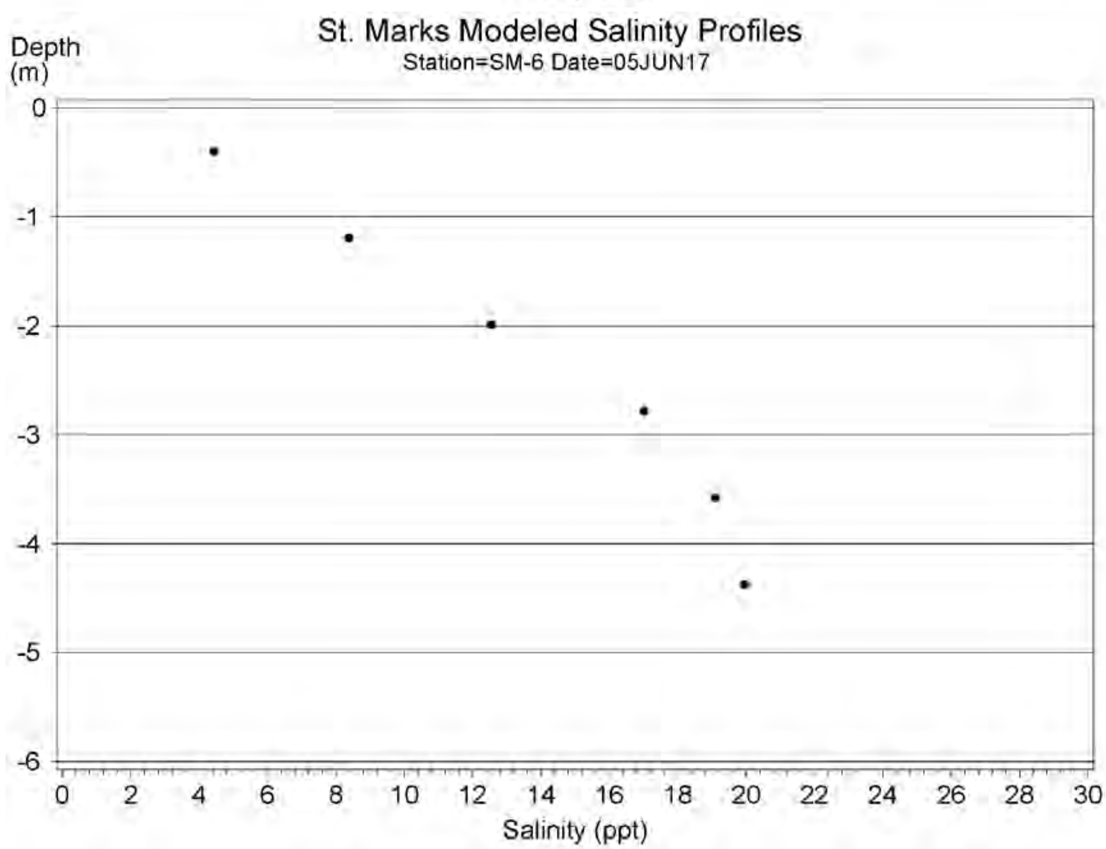

St. Marks Observed Salinity Profiles
Station=SM-4 Date=18MAY16
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

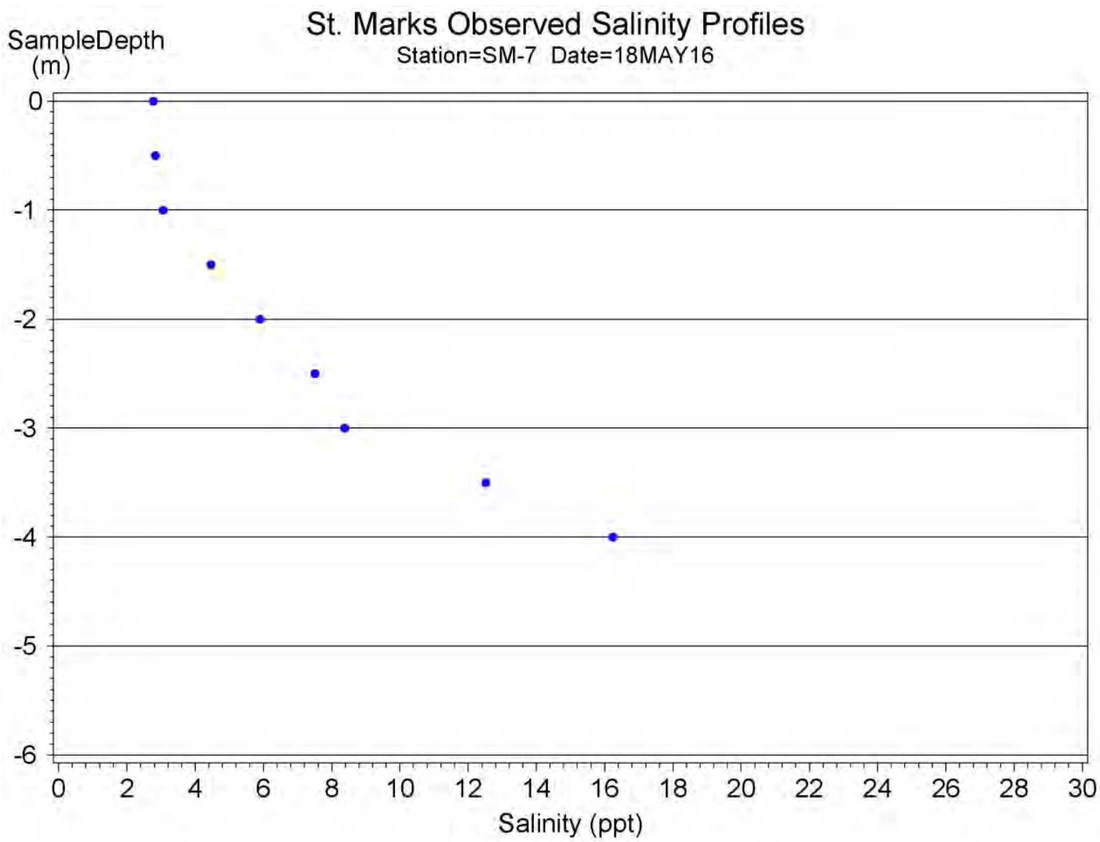

St. Marks Modeled Salinity Profiles
Station=SM-4 Date=05JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

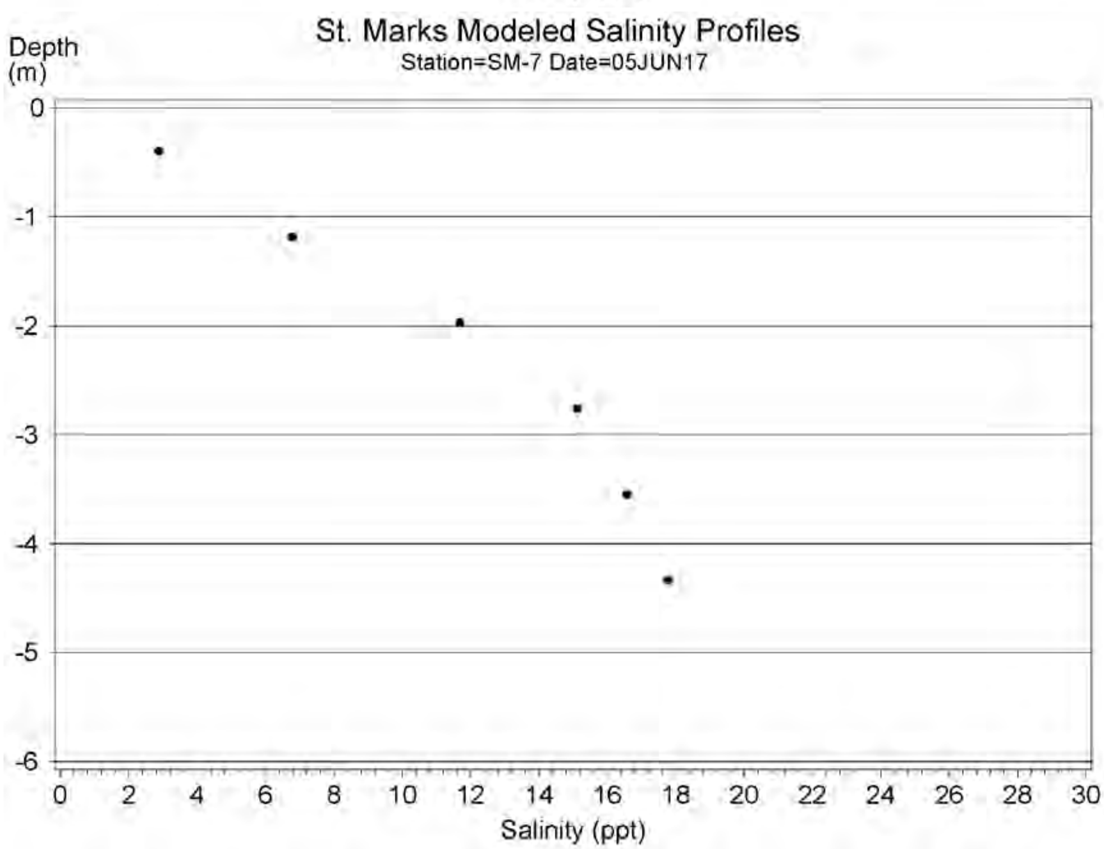

St. Marks Observed Salinity Profiles
Station=SM-5 Date=18MAY16
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

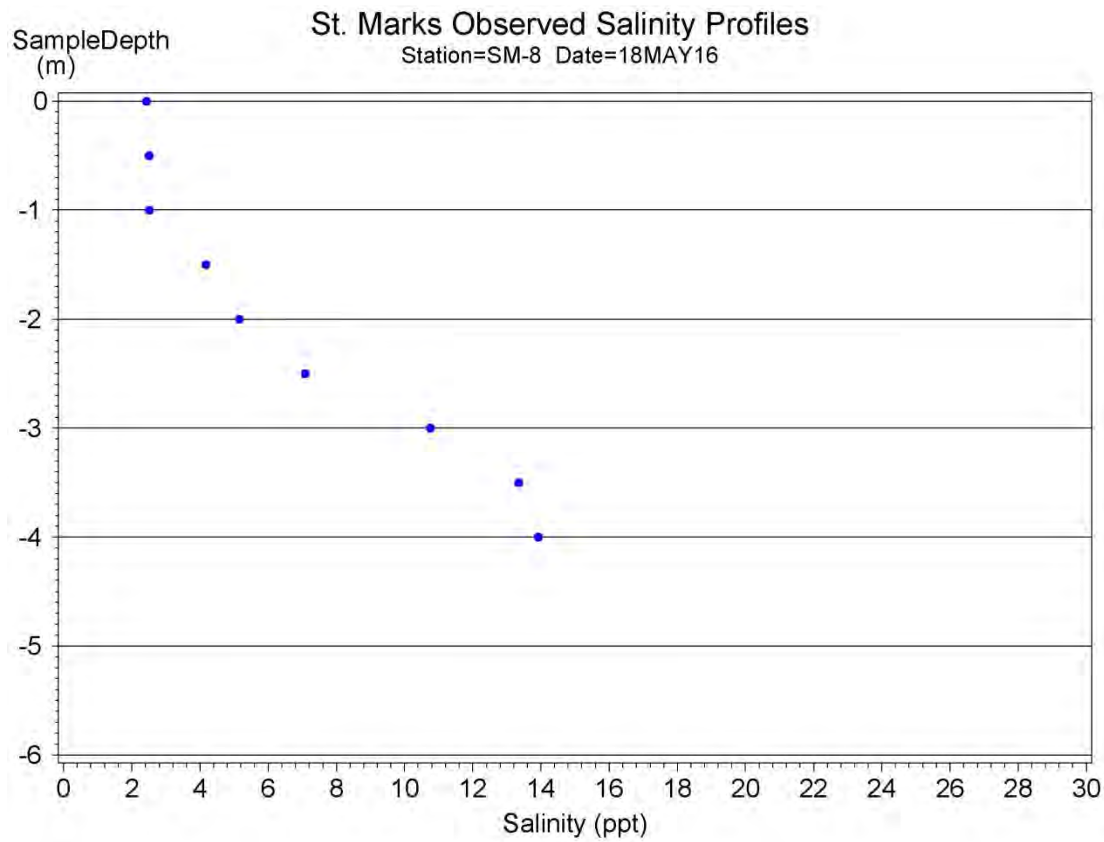

St. Marks Modeled Salinity Profiles
Station=SM-5 Date=05JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-6 Date=18MAY16
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

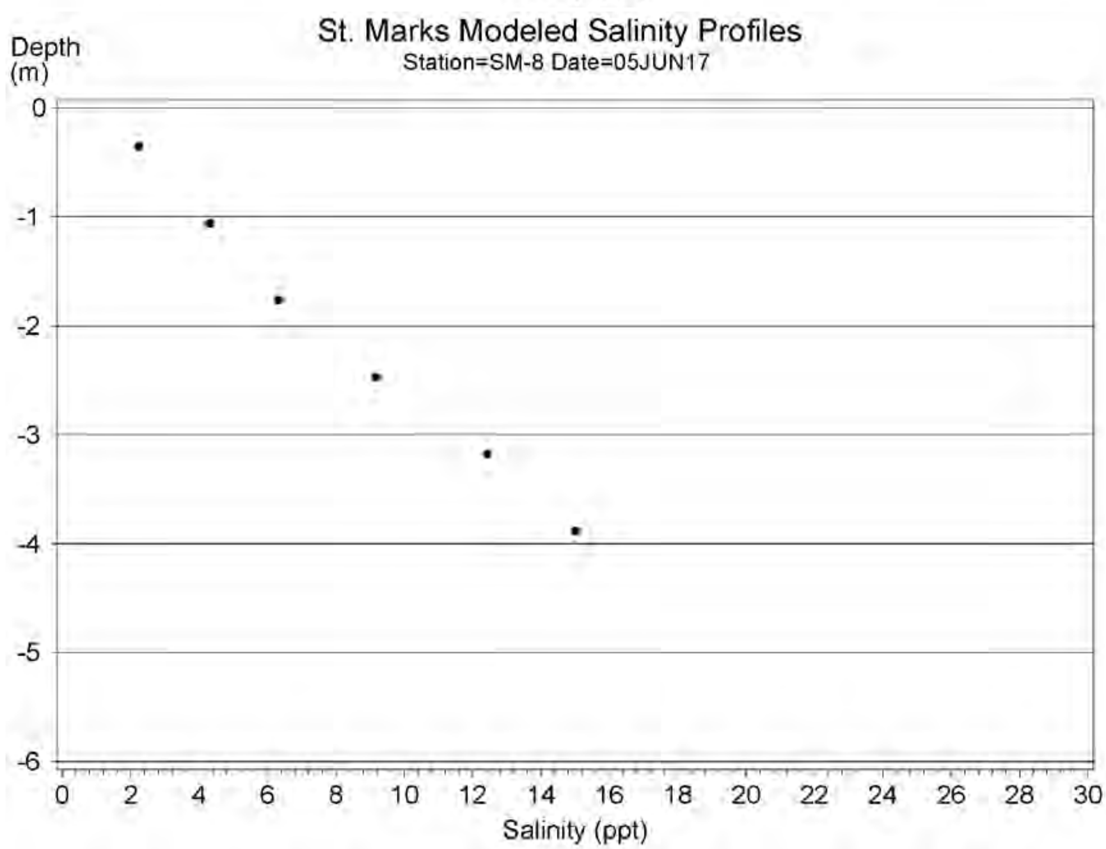

St. Marks Modeled Salinity Profiles
Station=SM-6 Date=05JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-7 Date=18MAY16
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

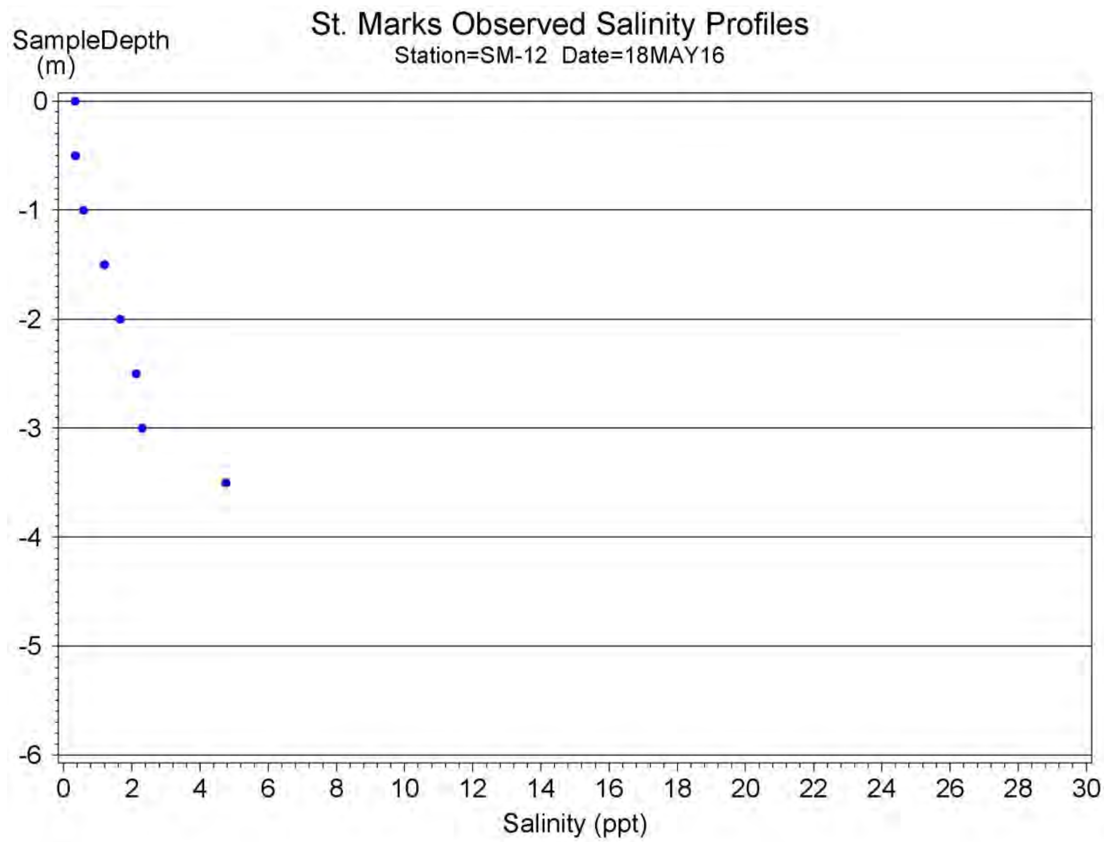

St. Marks Modeled Salinity Profiles
Station=SM-7 Date=05JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

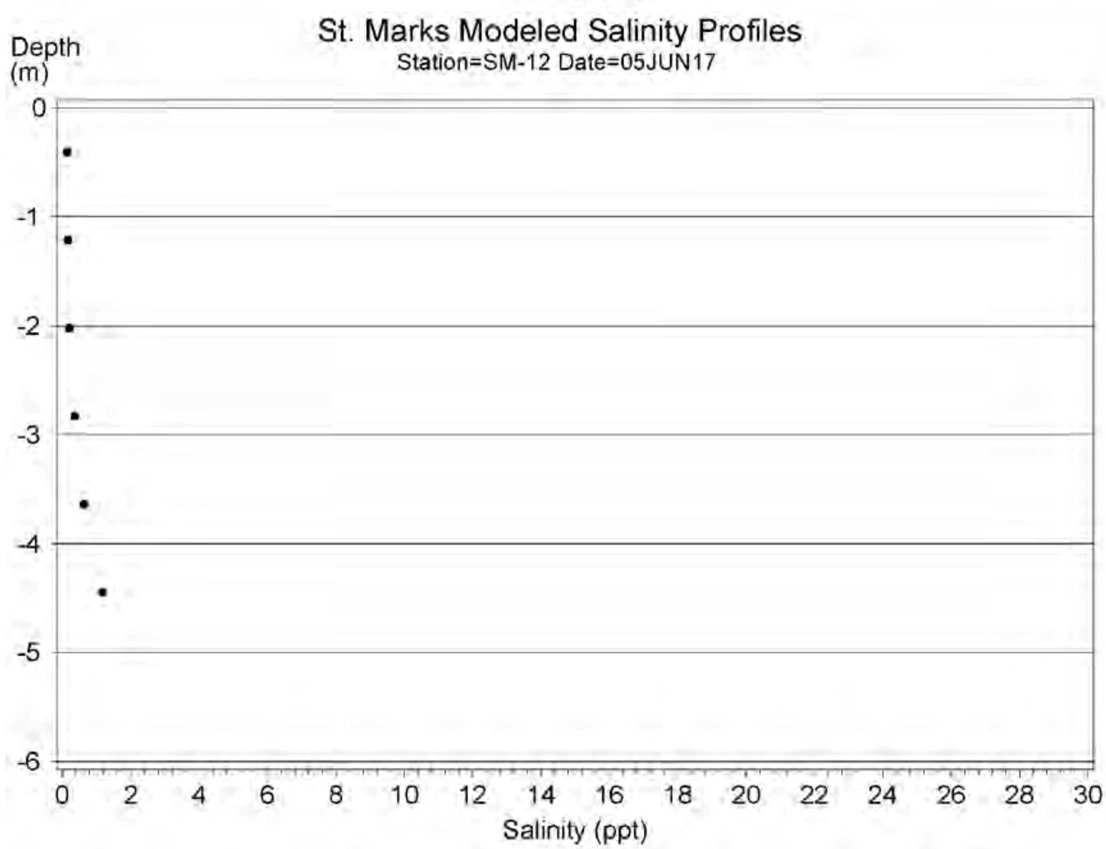


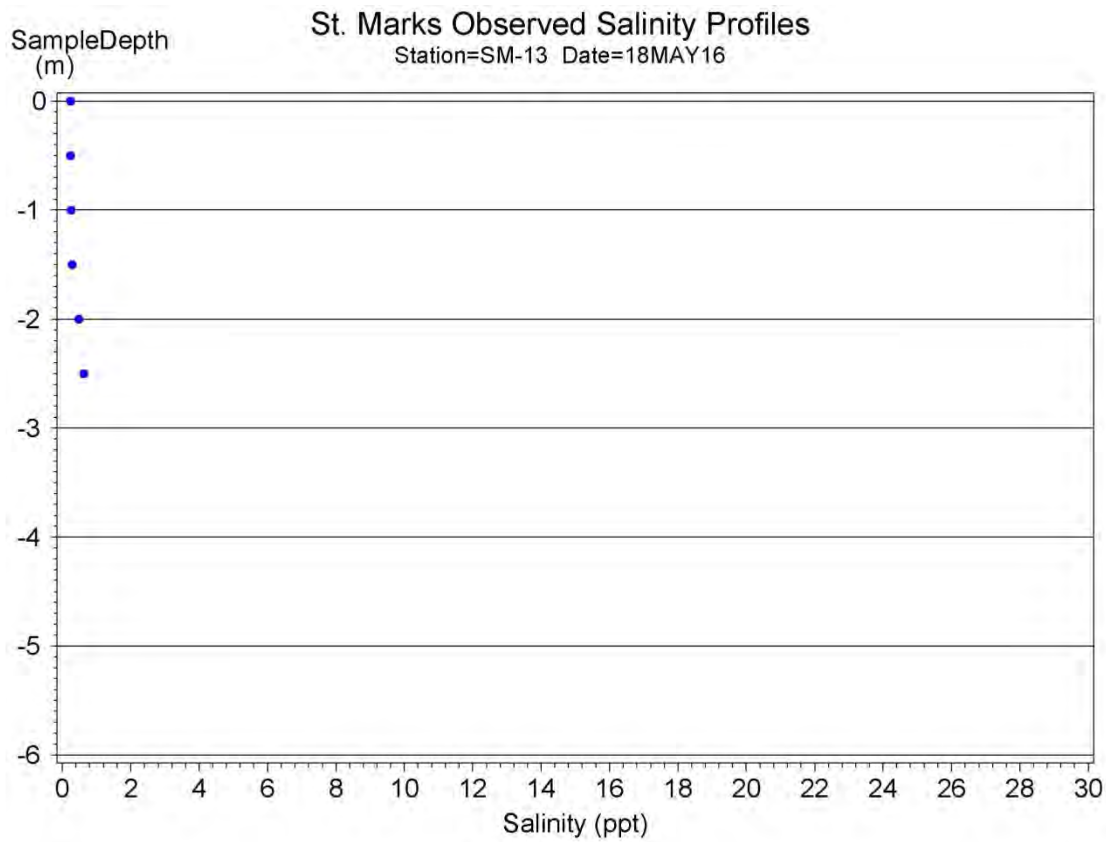
St. Marks Observed Salinity Profiles
Station=SM-8 Date=18MAY16
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

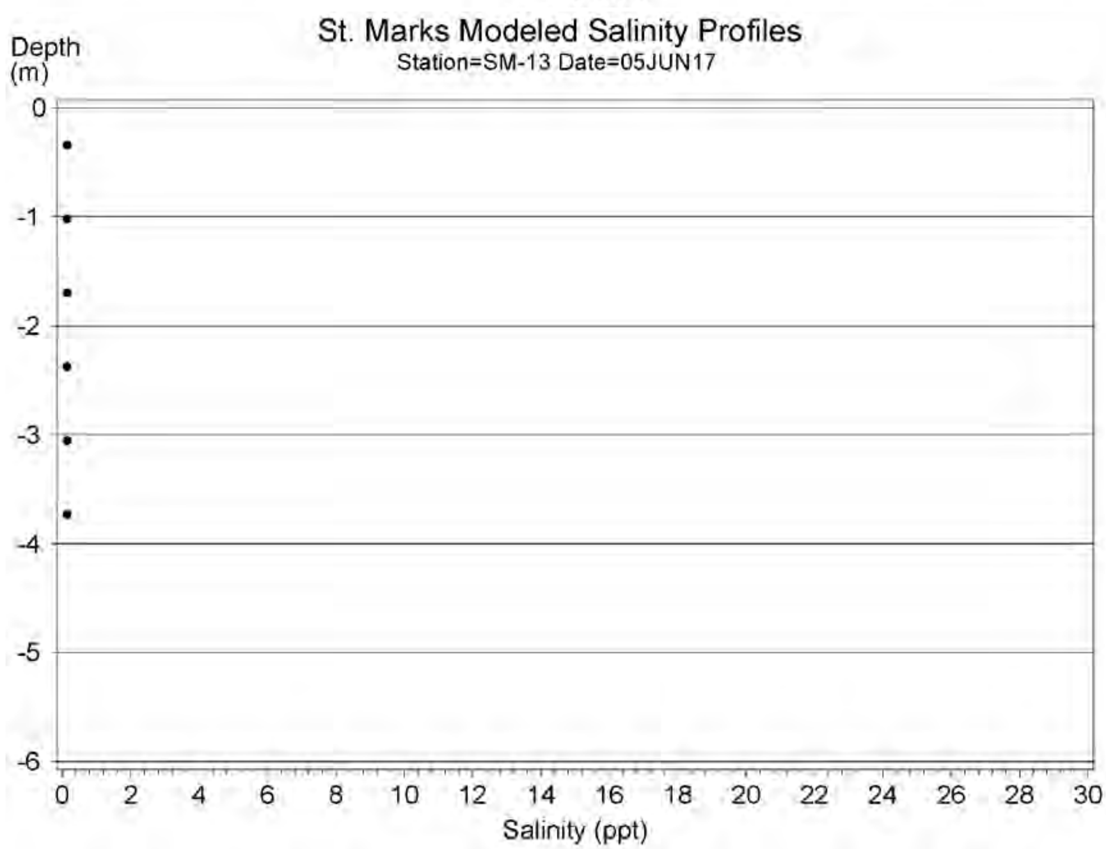


St. Marks Modeled Salinity Profiles
Station=SM-8 Date=05JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-12 Date=18MAY16
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-12 Date=05JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-13 Date=18MAY16
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-13 Date=05JUN17
Depth (m)
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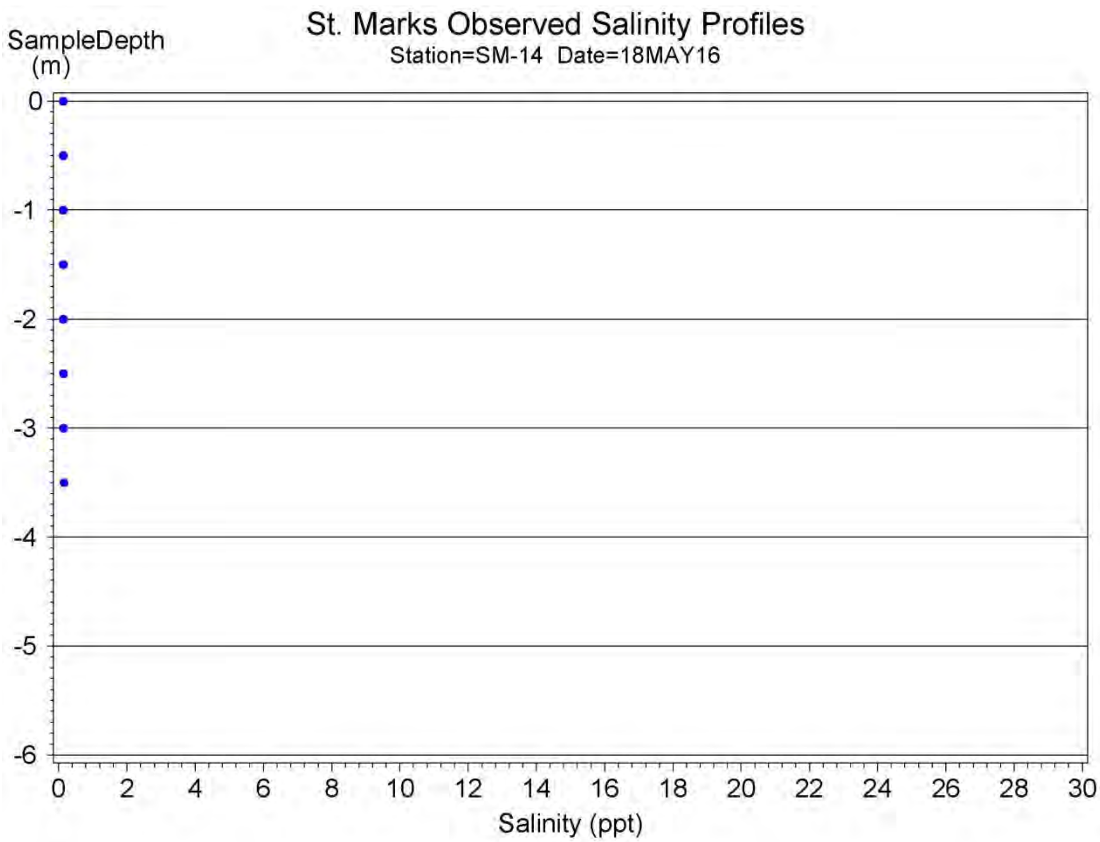
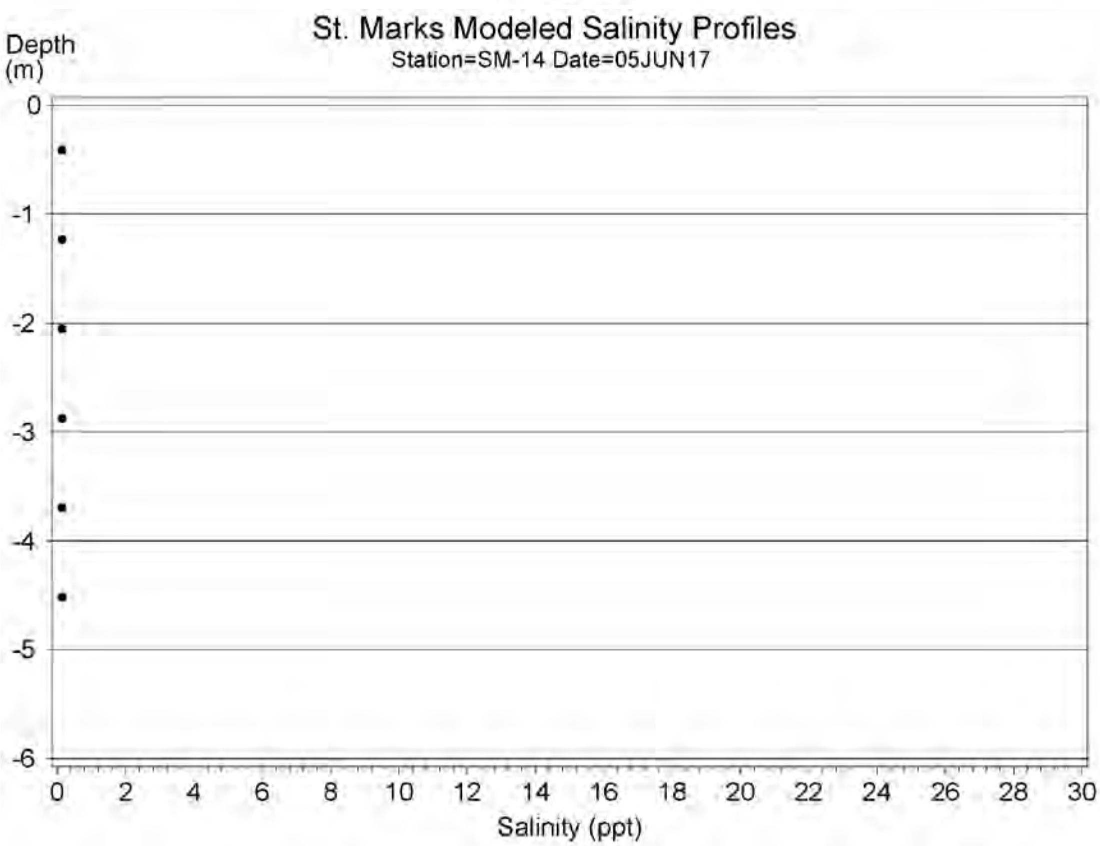
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-14 Date=18MAY16
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-14 Date=05JUN17
Depth (m)
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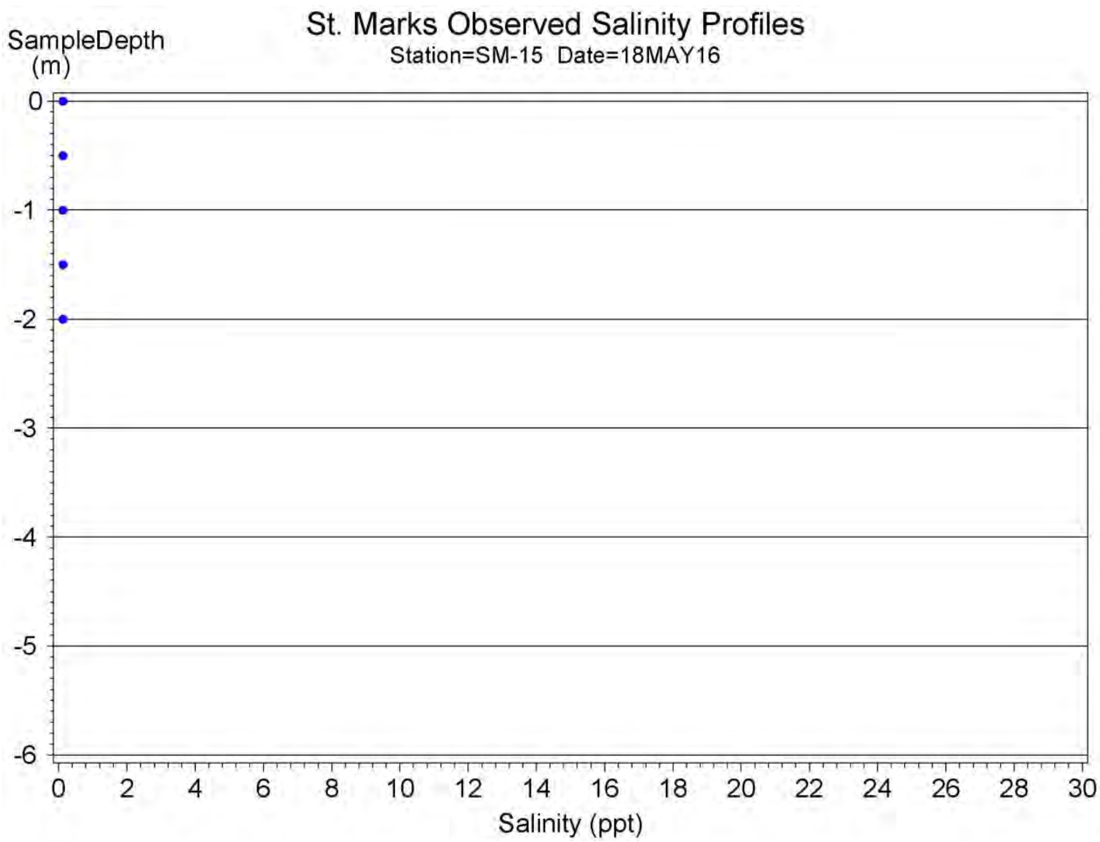
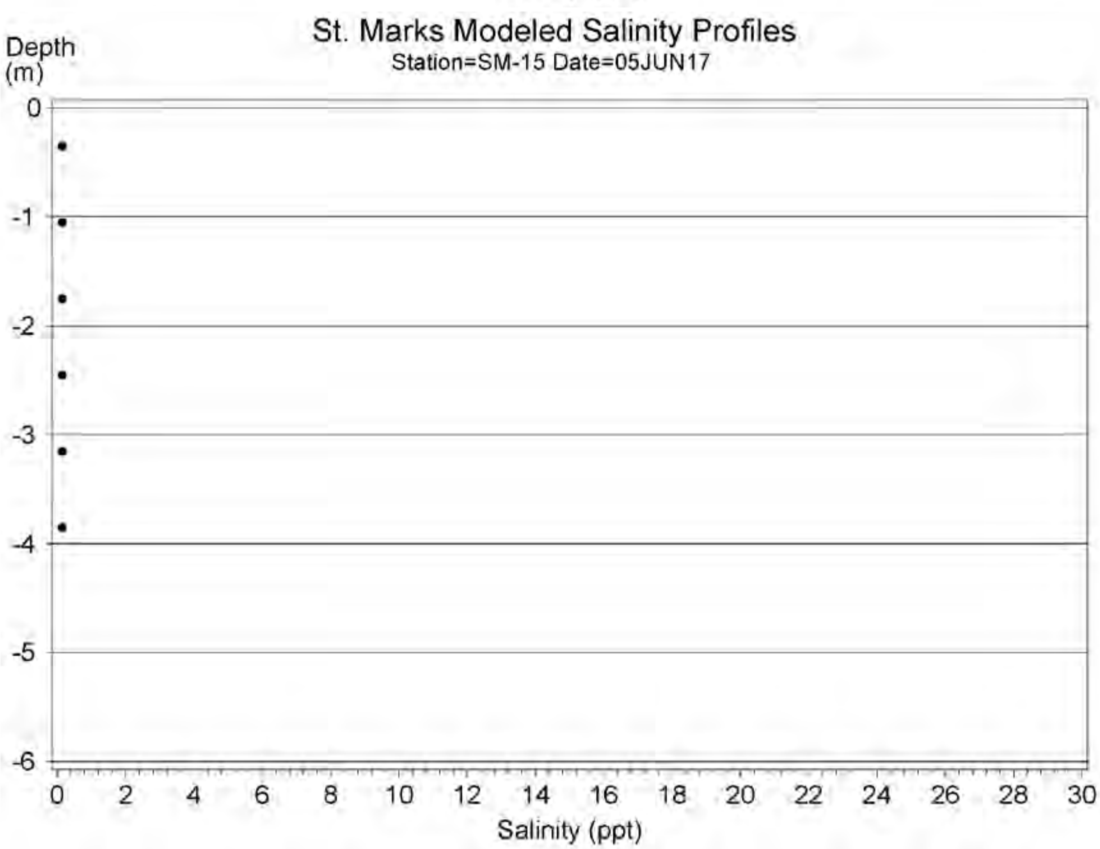
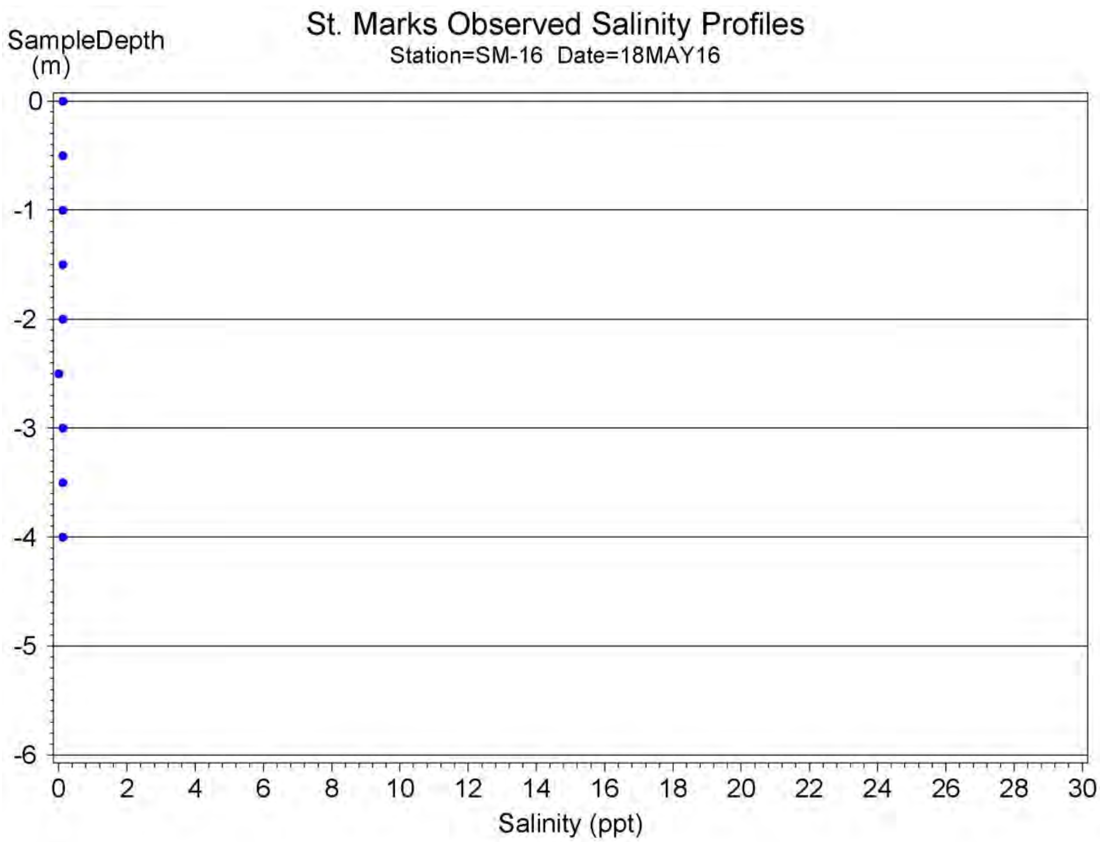
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-15 Date=18MAY16
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-15 Date=05JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-16 Date=18MAY16
SampleDepth (m)
0
-1
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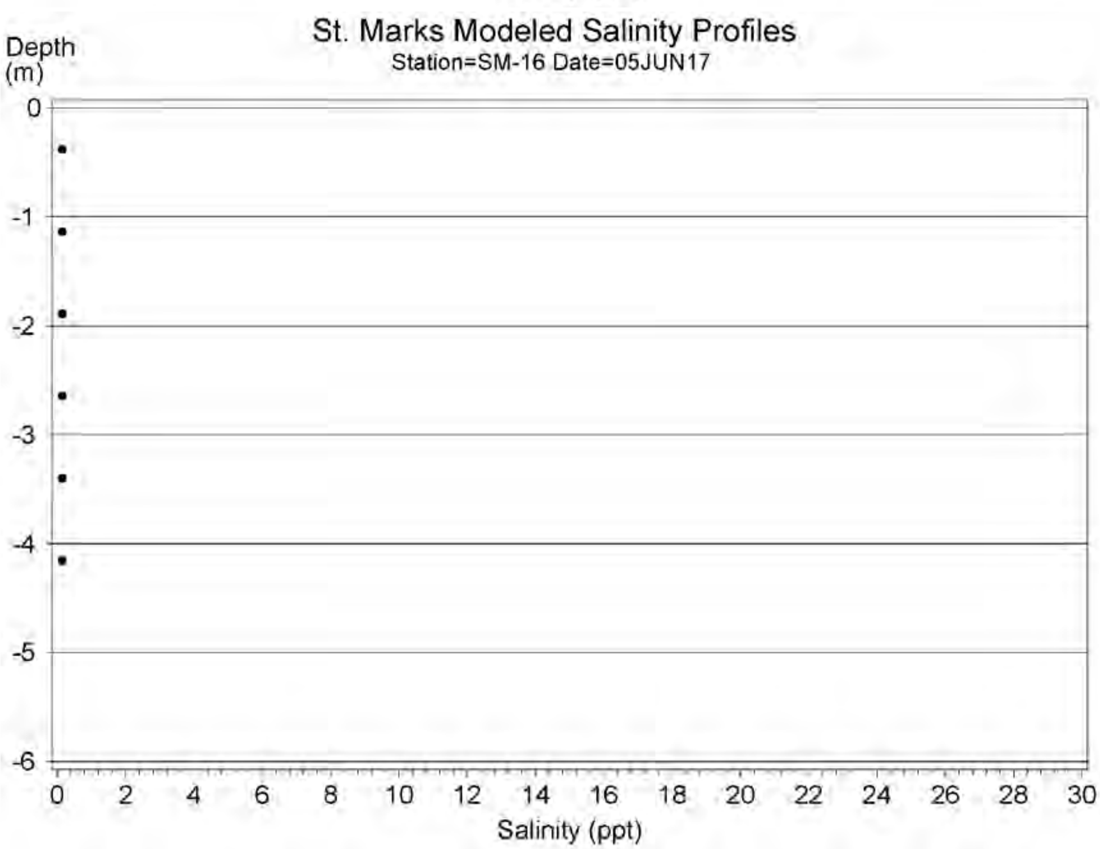
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-16 Date=05JUN17
Depth (m)
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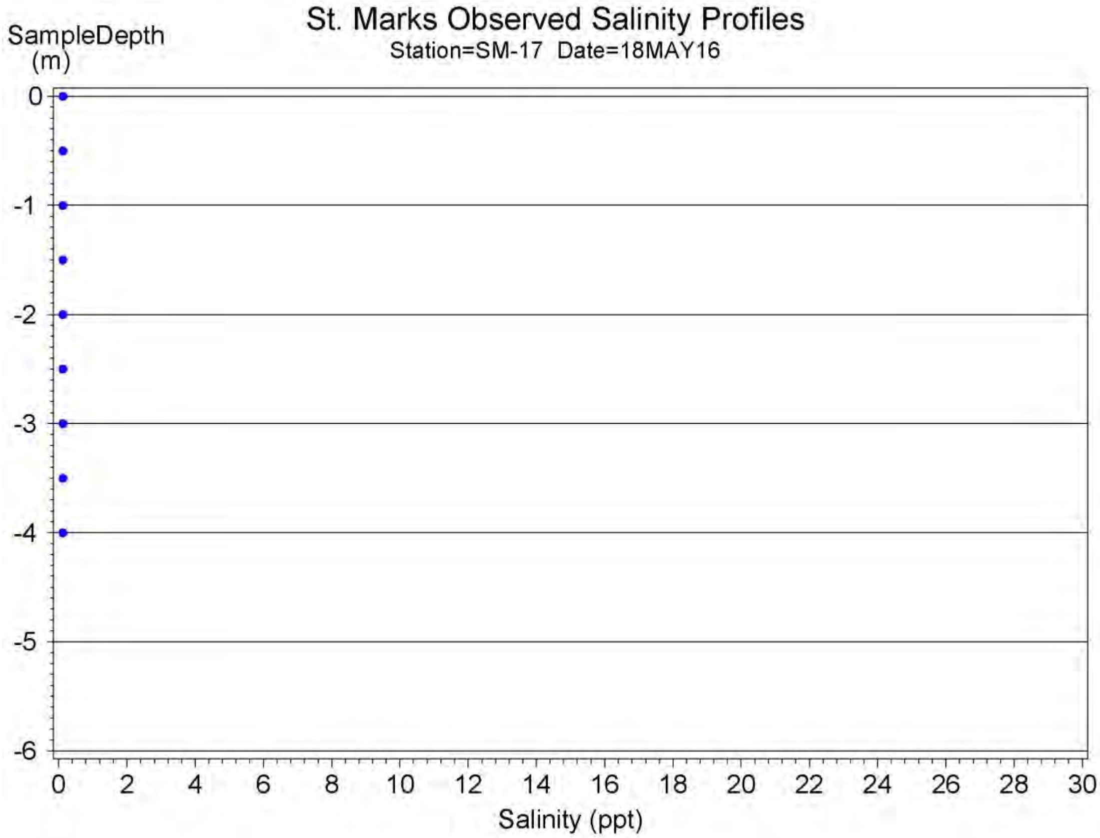
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-17 Date=18MAY16
SampleDepth
(m)
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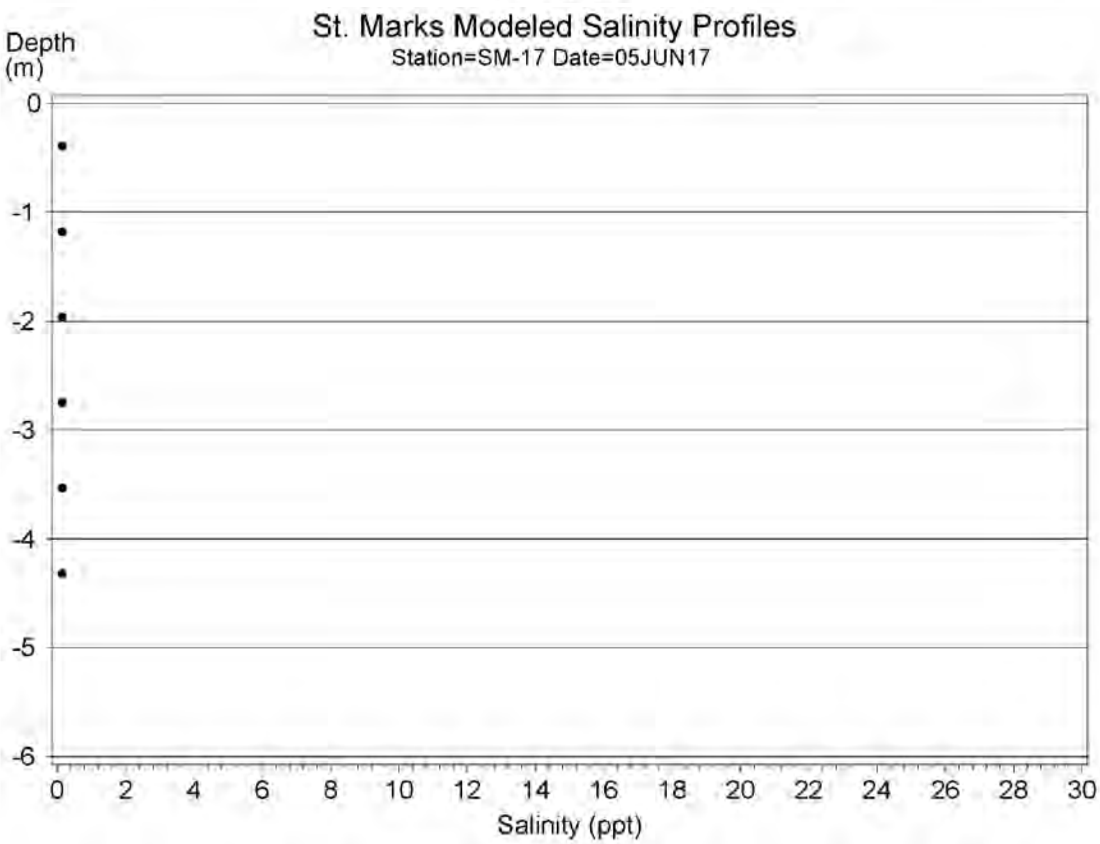
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-17 Date=05JUN17
Depth
(m)
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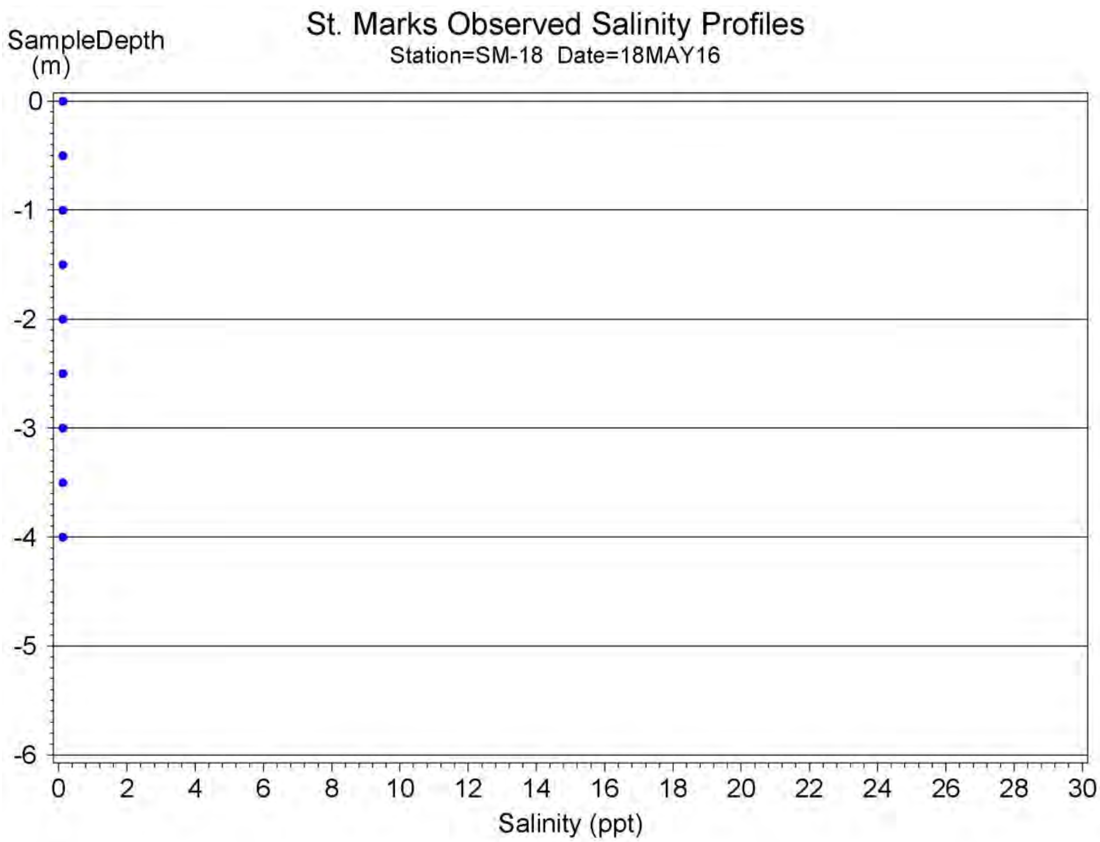
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-18 Date=18MAY16
SampleDepth (m)
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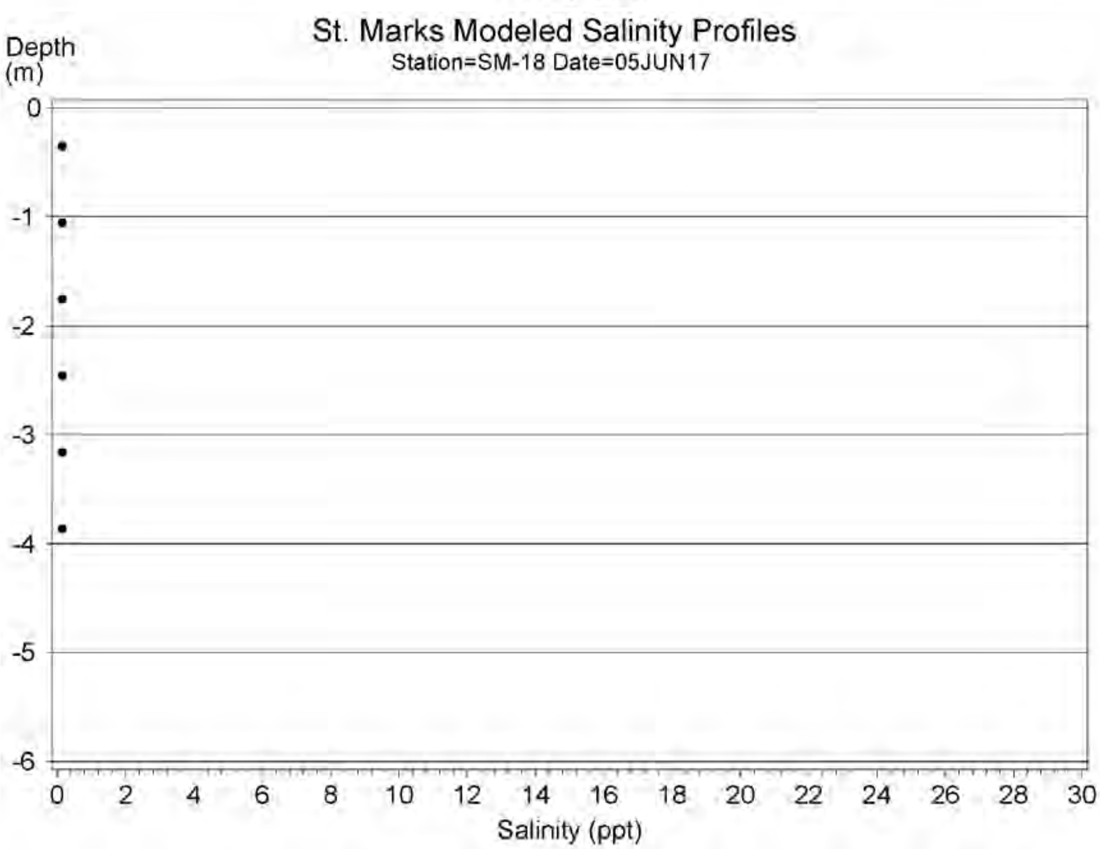
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-18 Date=05JUN17
Depth (m)
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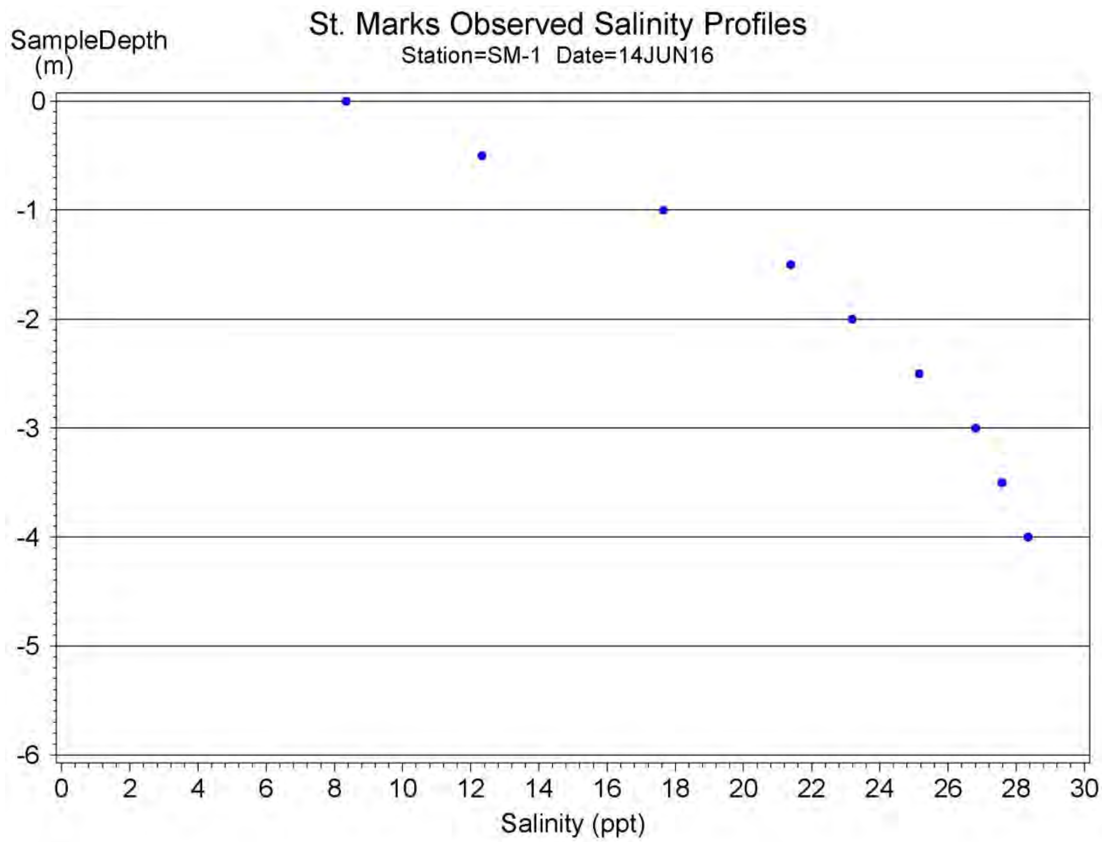
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-1 Date=14JUN16
SampleDepth (m)
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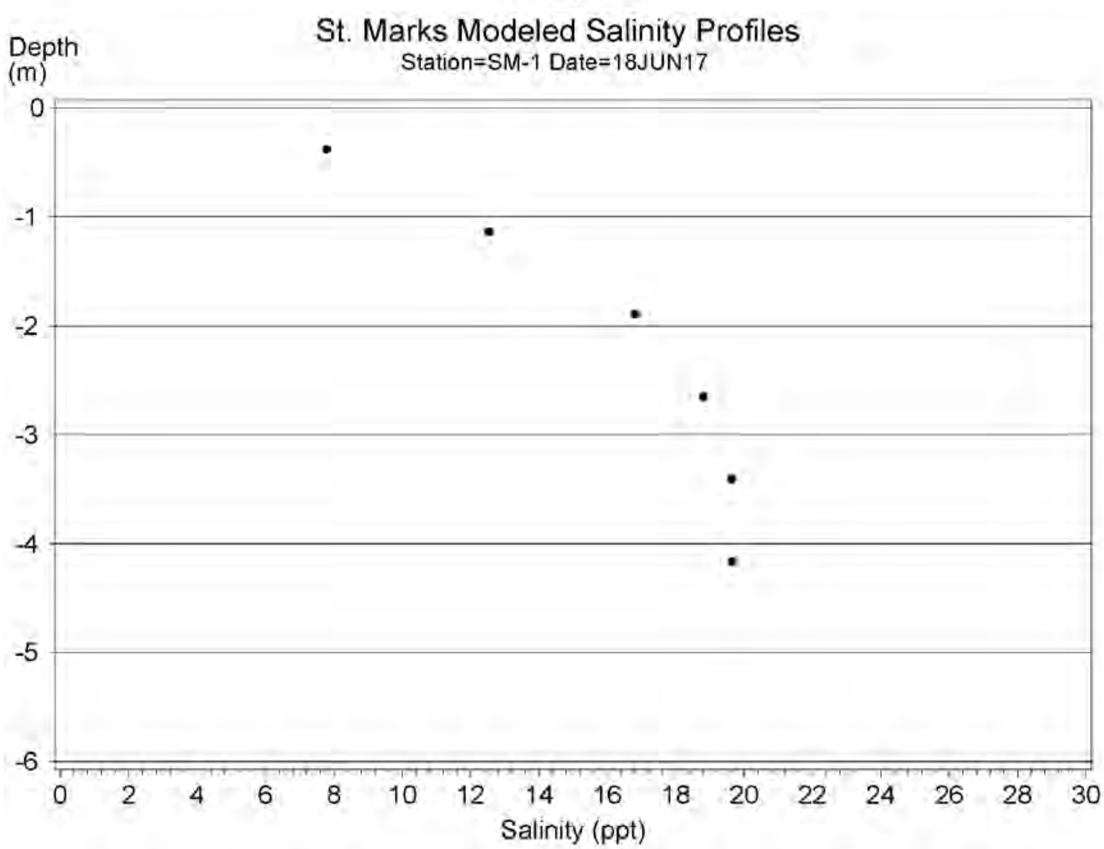
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-1 Date=18JUN17
Depth (m)
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-2
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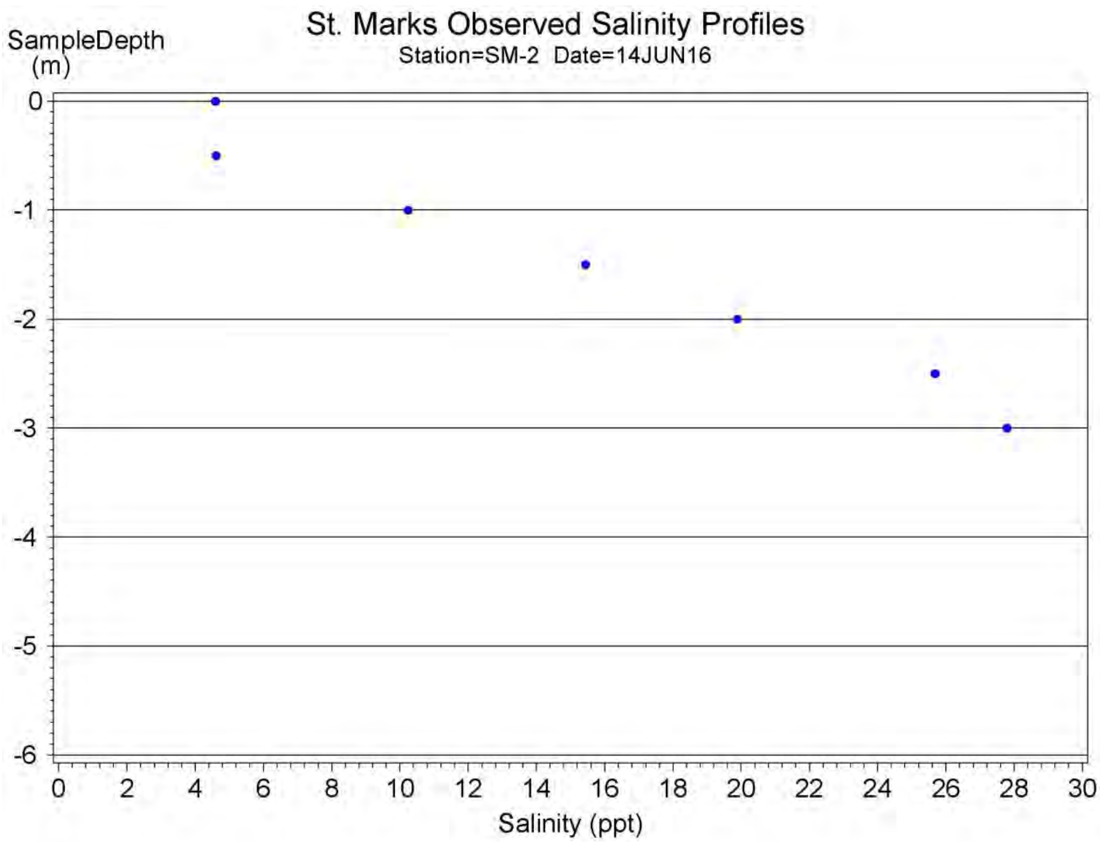
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-2 Date=14JUN16
SampleDepth (m)
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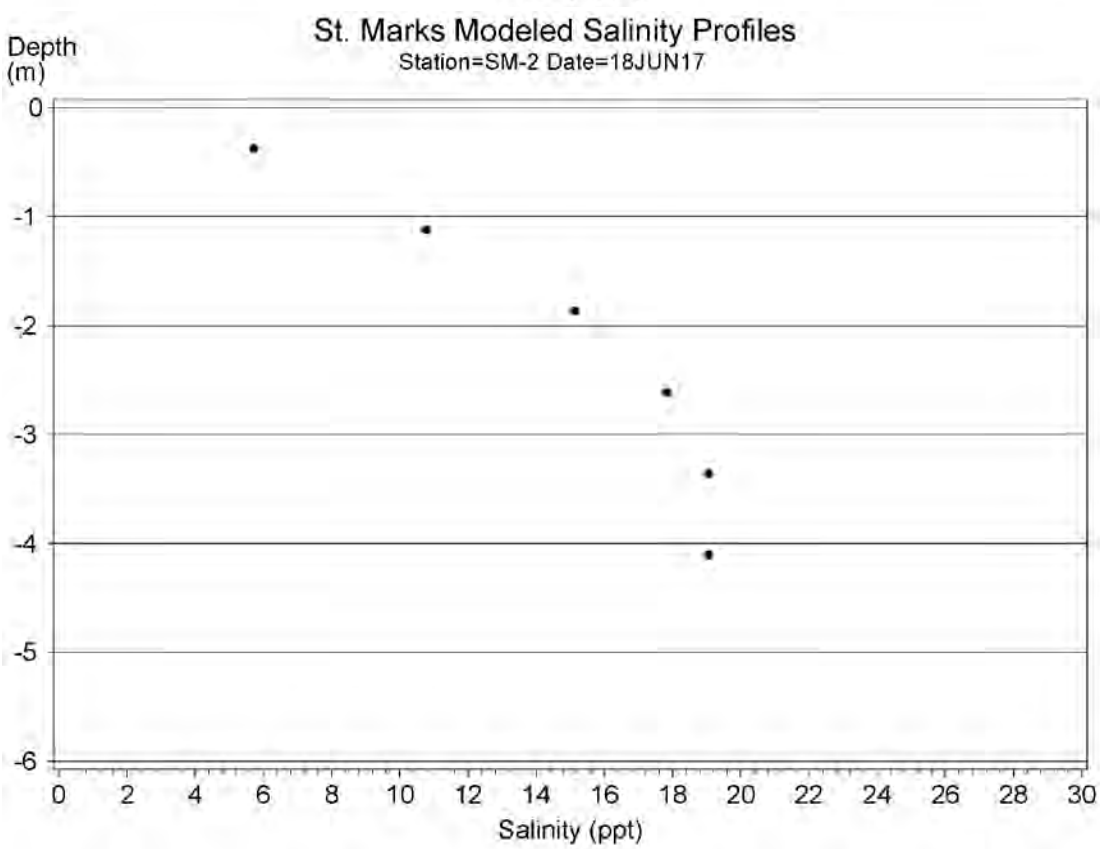
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-2 Date=18JUN17
Depth (m)
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-2
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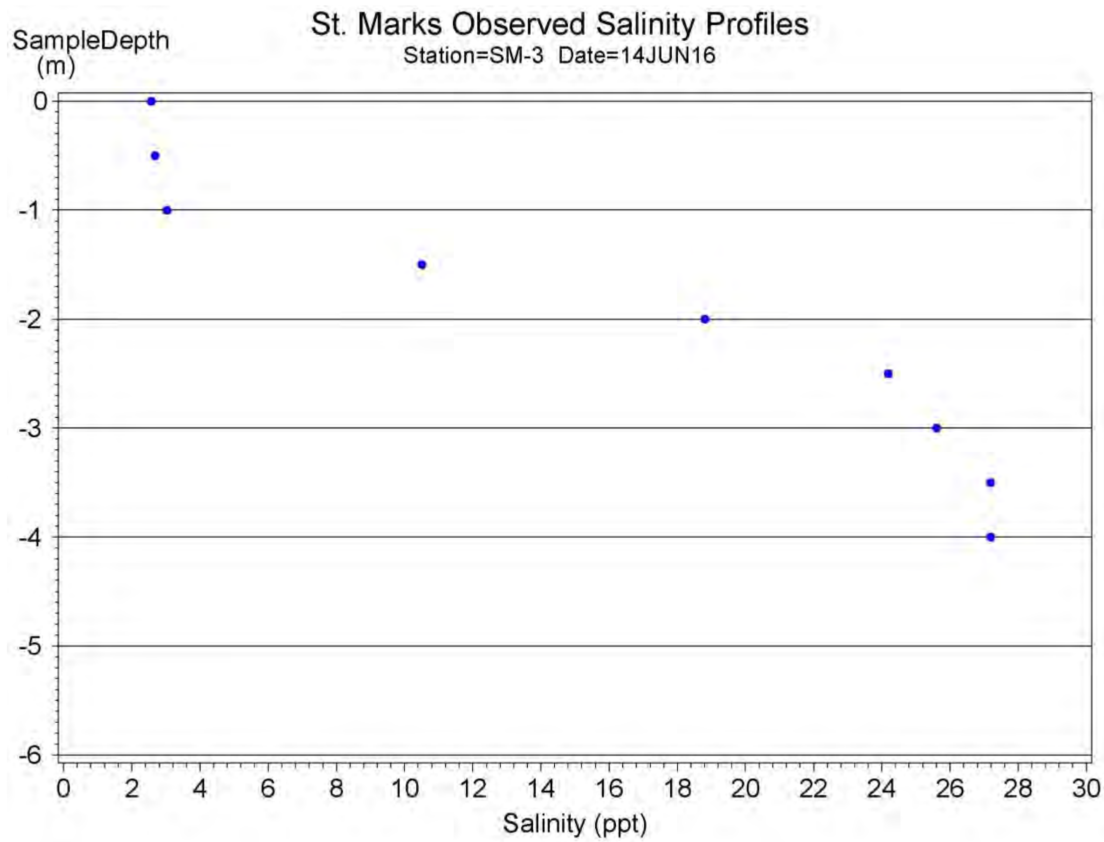
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-3 Date=14JUN16
SampleDepth (m)
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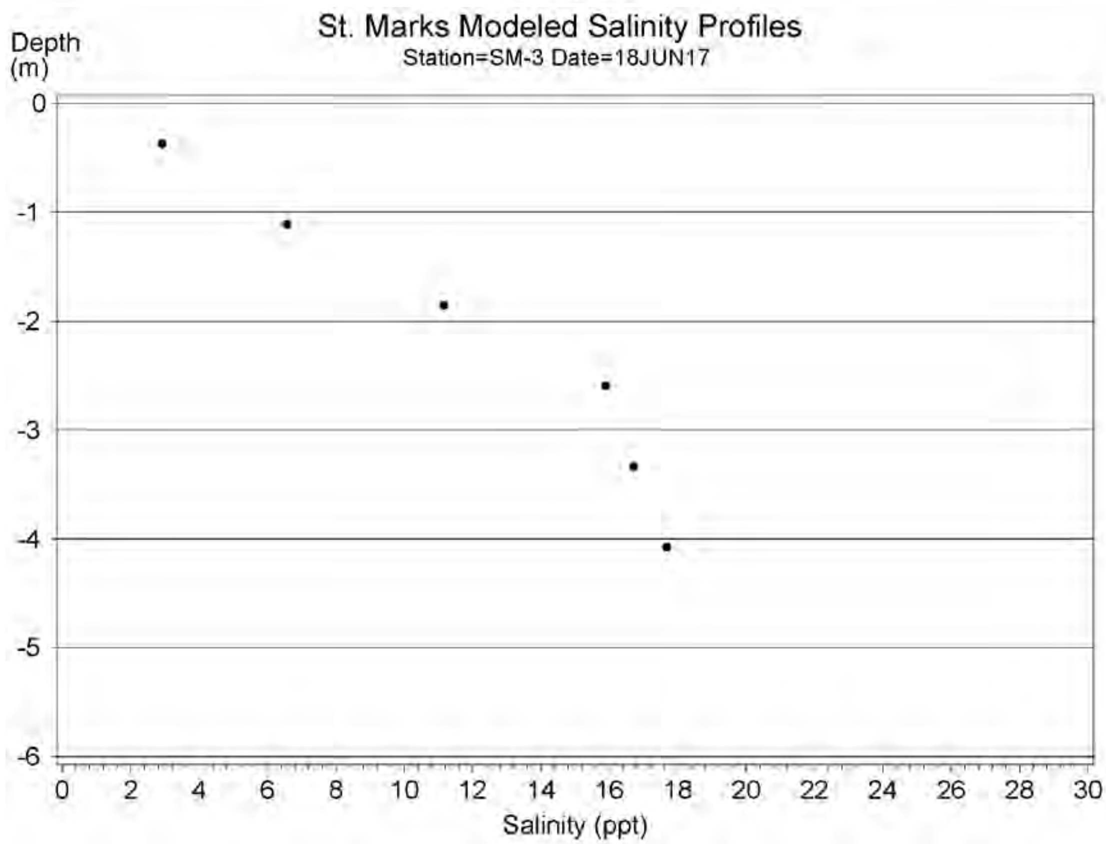
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-3 Date=18JUN17
Depth (m)
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-2
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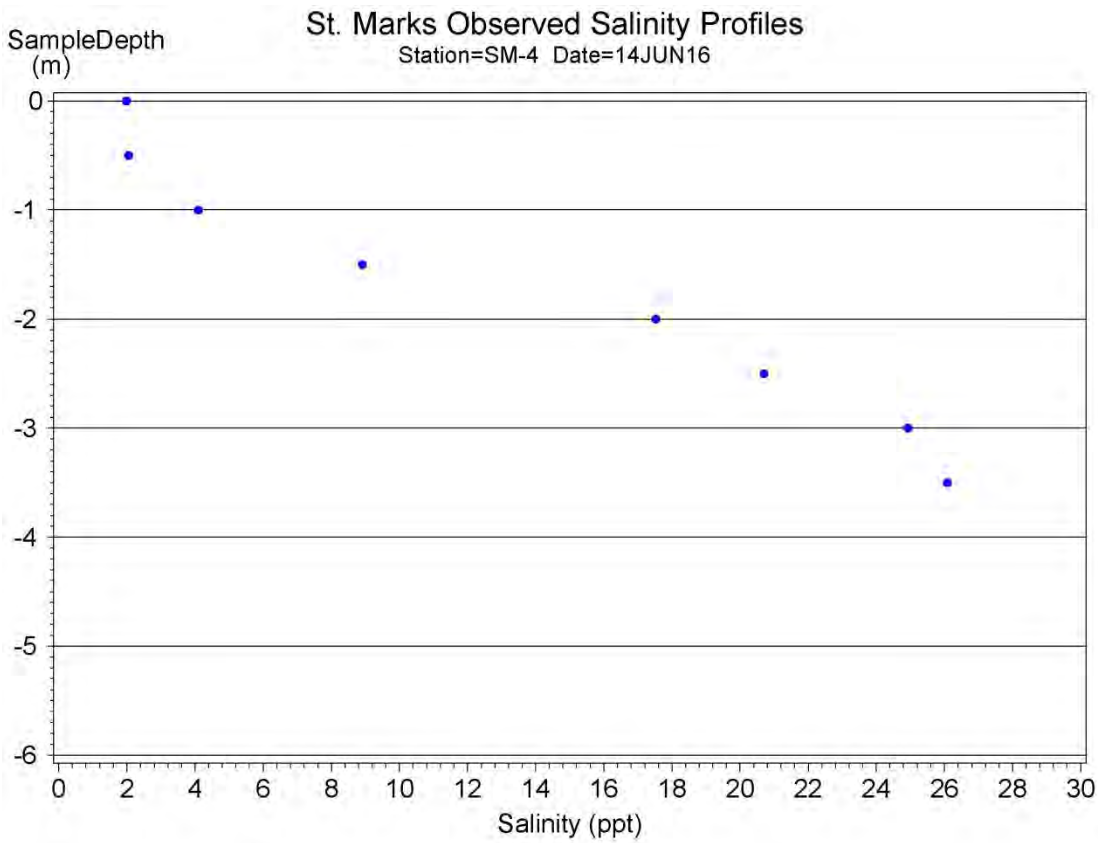
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-4 Date=14JUN16
SampleDepth (m)
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-1
-2
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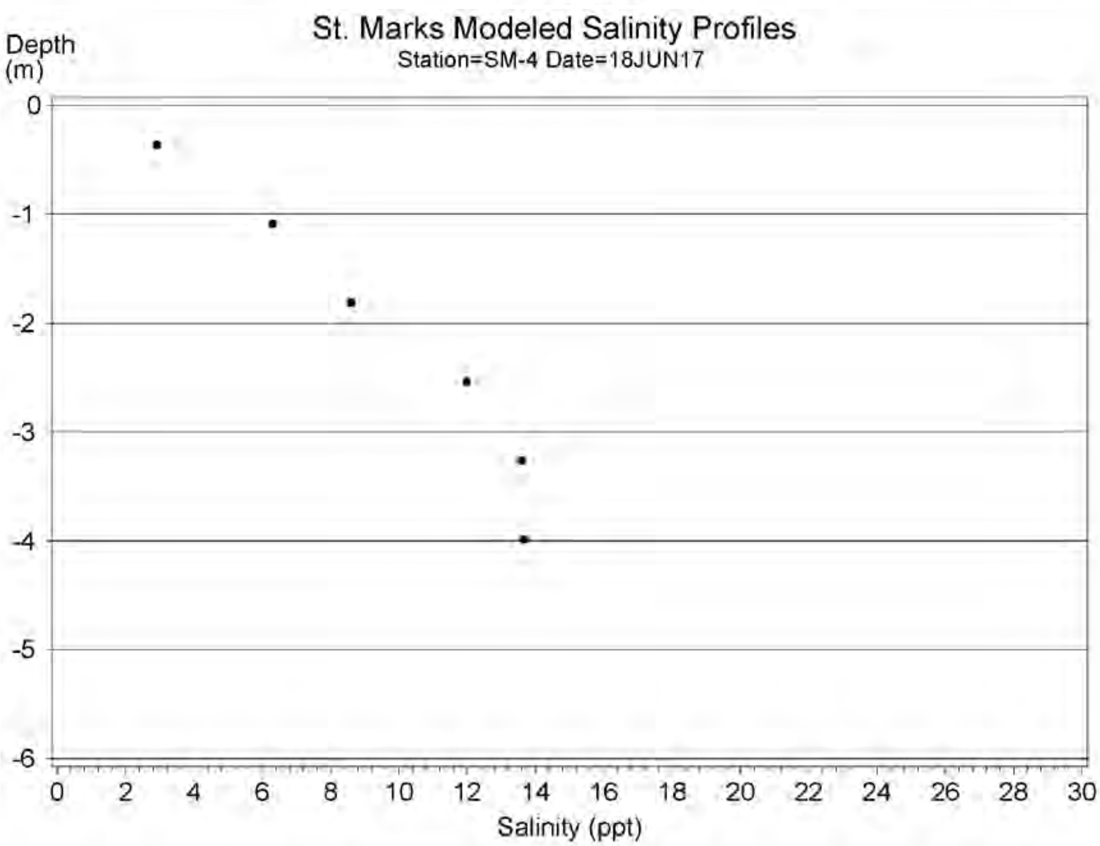
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-4 Date=18JUN17
Depth (m)
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-1
-2
-3
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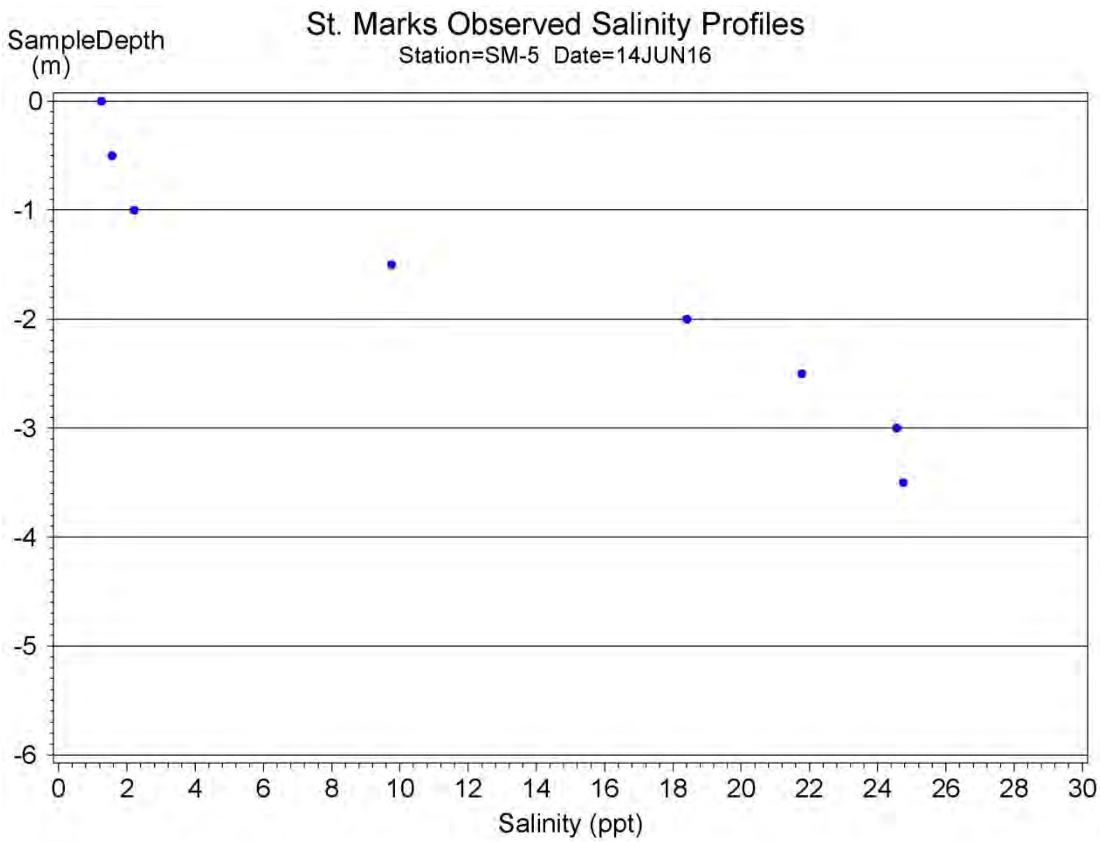
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-5 Date=14JUN16
SampleDepth (m)
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-1
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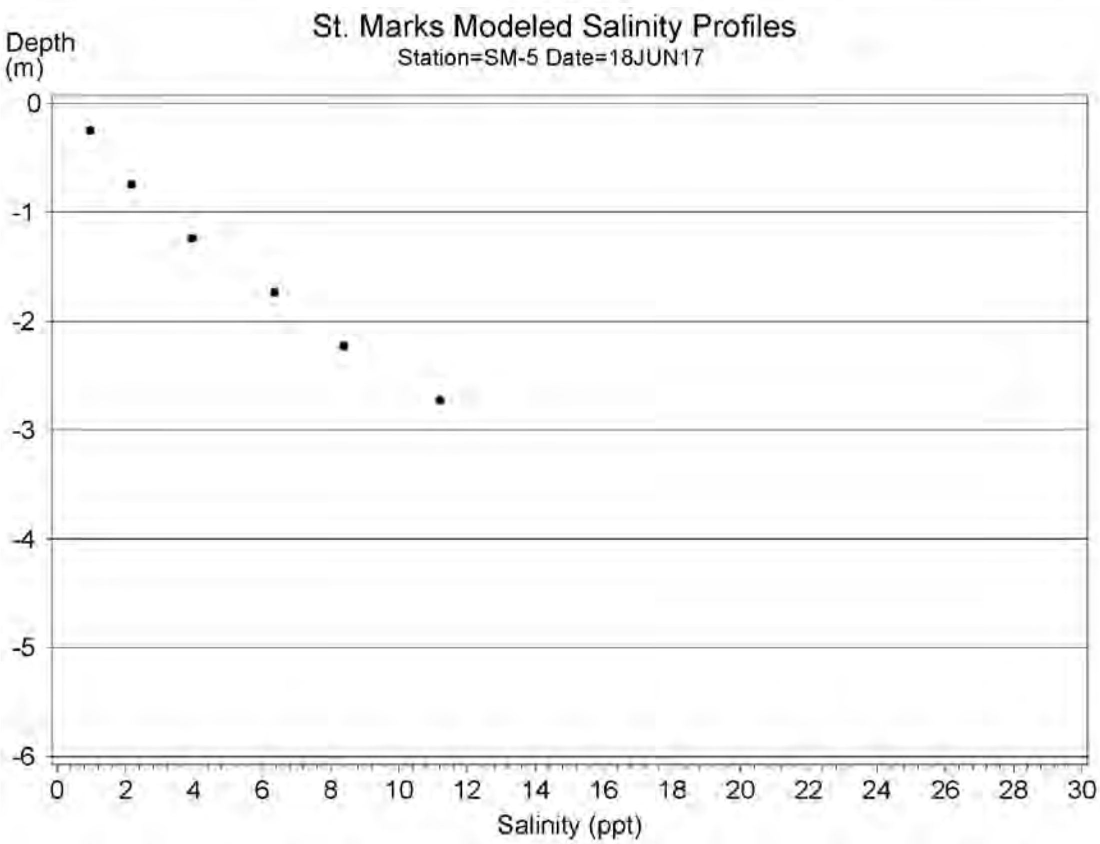
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-5 Date=18JUN17
Depth (m)
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-2
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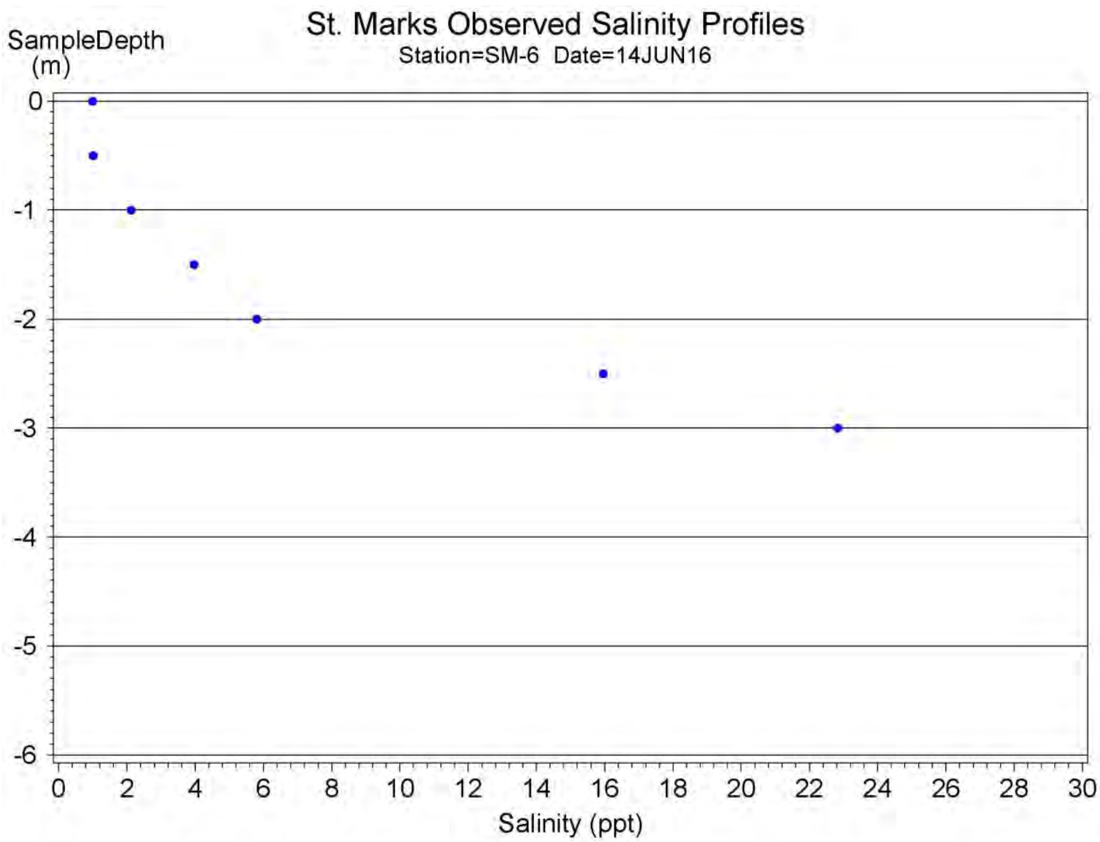
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-6 Date=14JUN16
SampleDepth (m)
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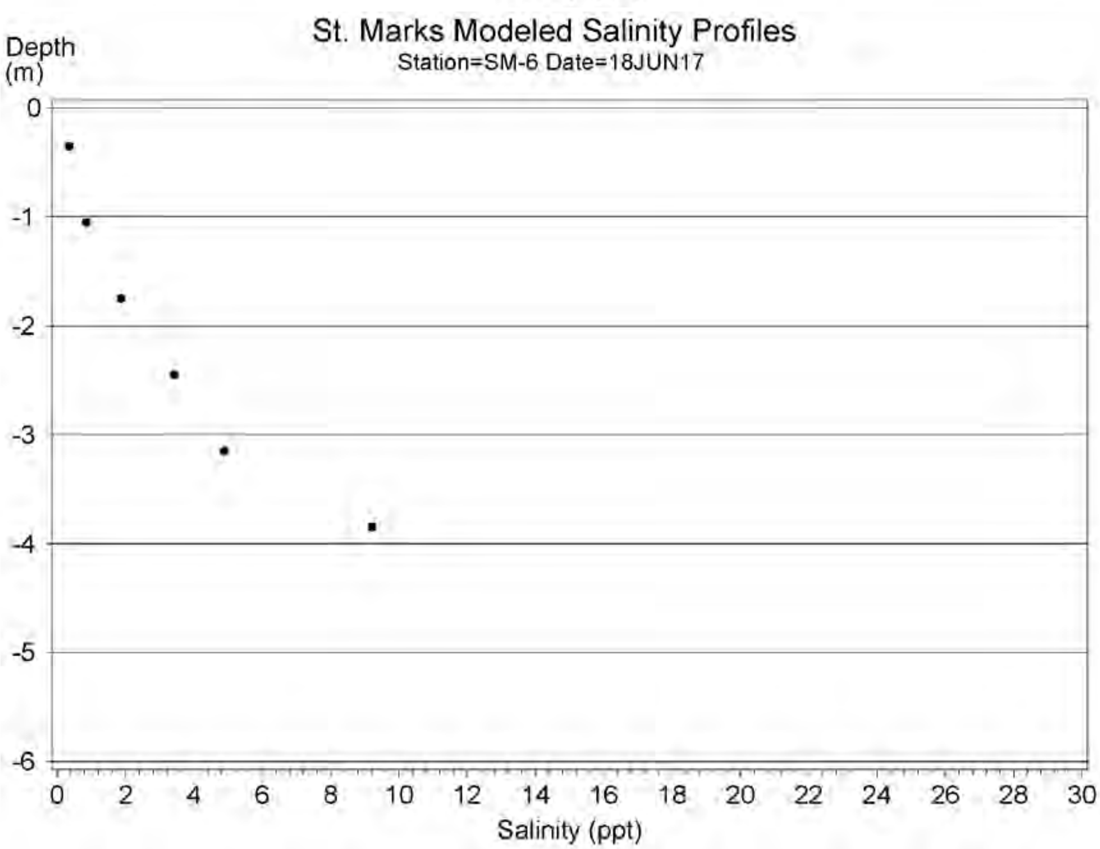
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-6 Date=18JUN17
Depth (m)
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-1
-2
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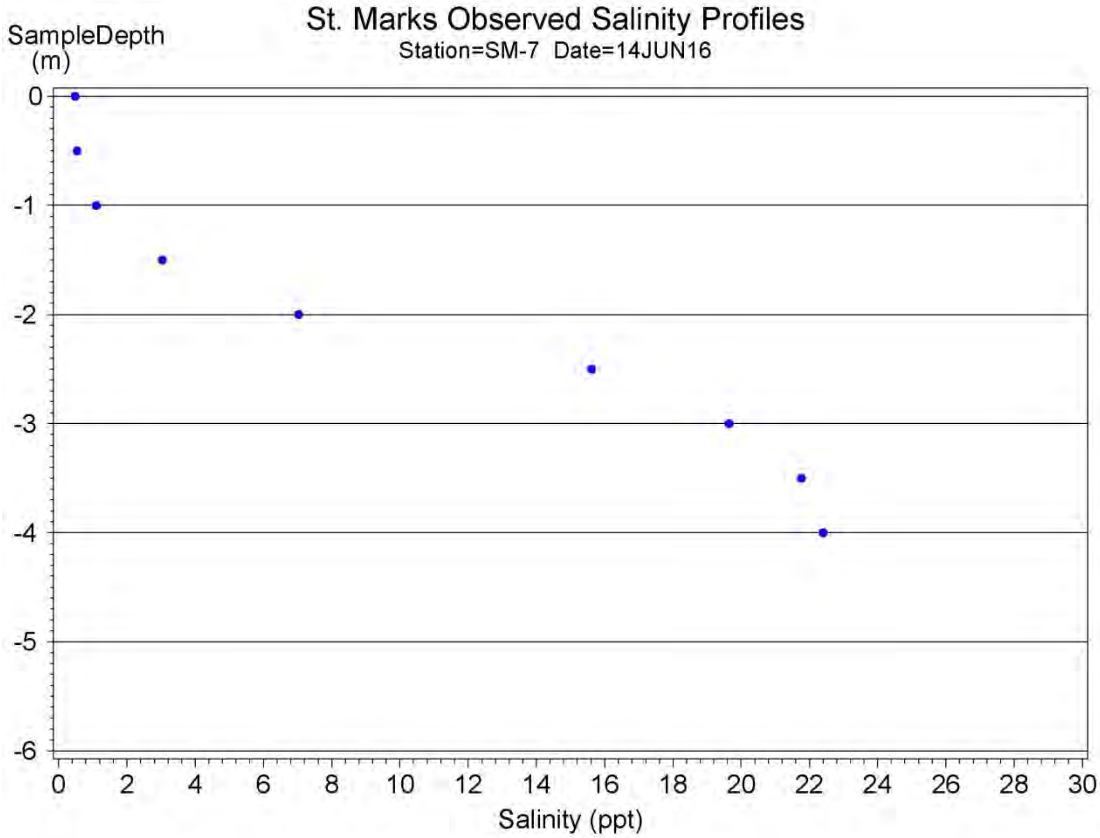
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-7 Date=14JUN16
SampleDepth (m)
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-1
-2
-3
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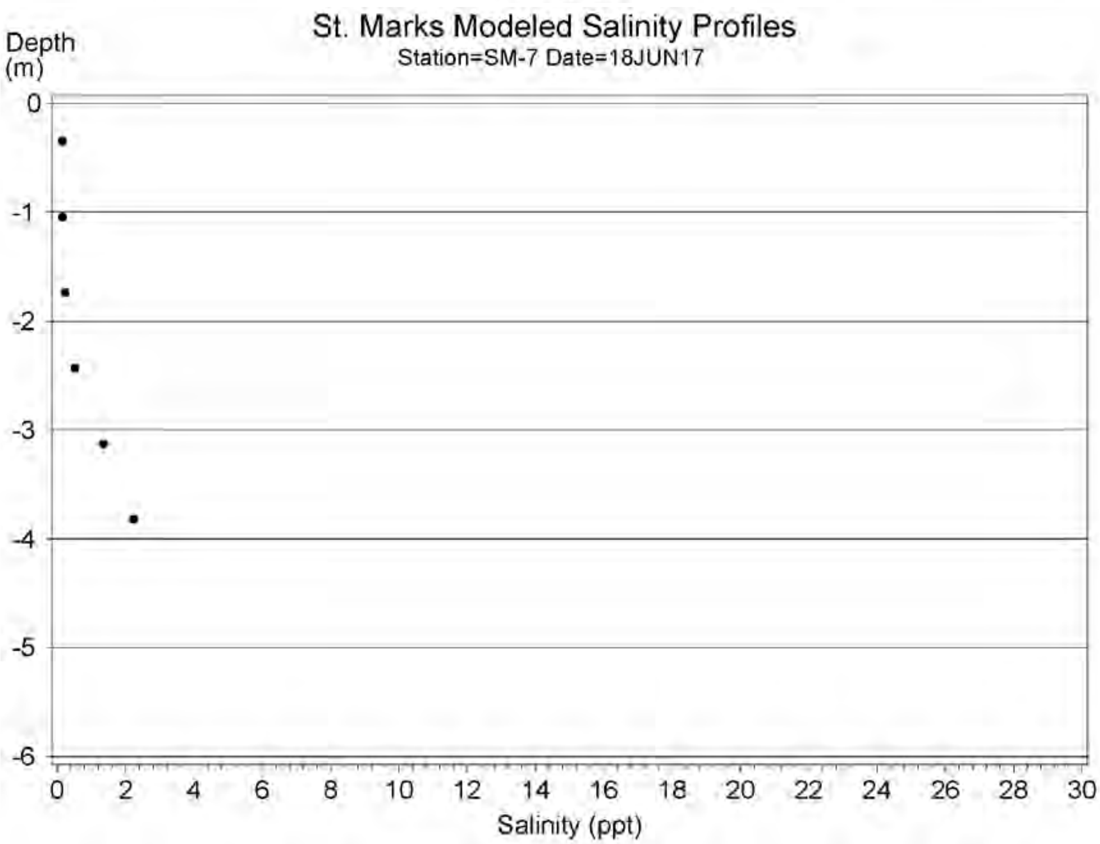
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-7 Date=18JUN17
Depth (m)
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-1
-2
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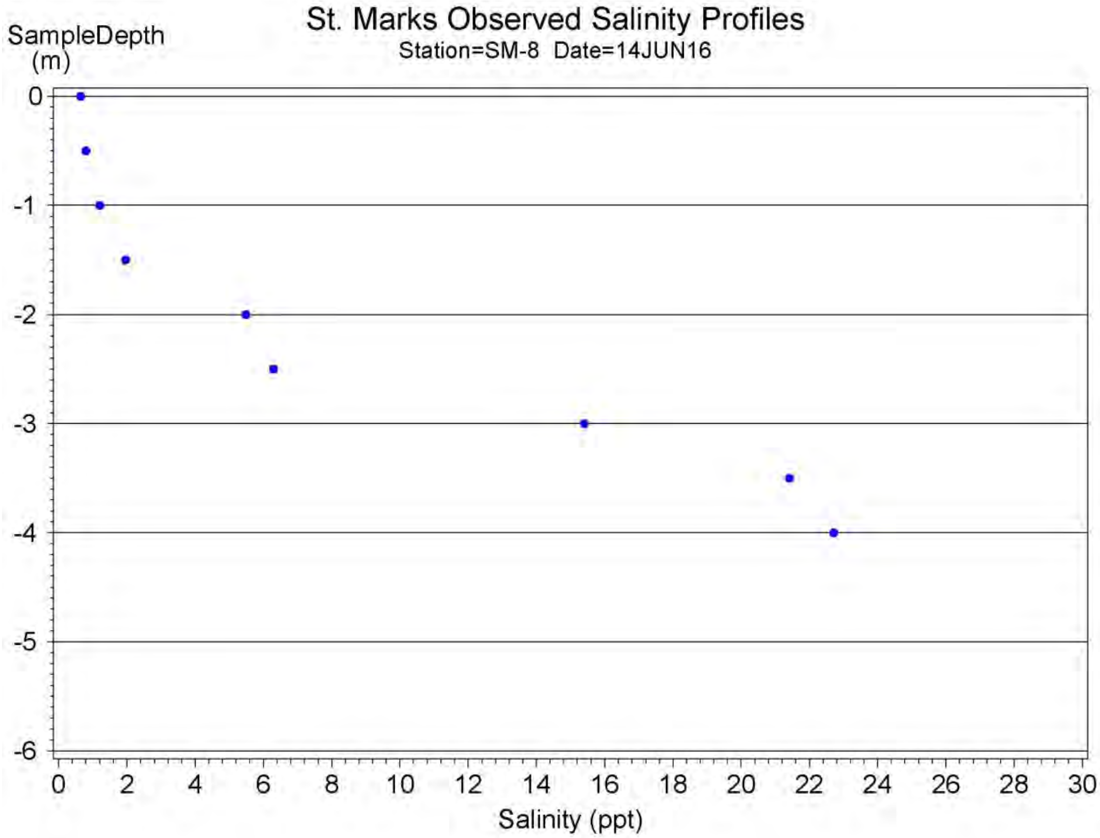
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-8 Date=14JUN16
SampleDepth (m)
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-2
-3
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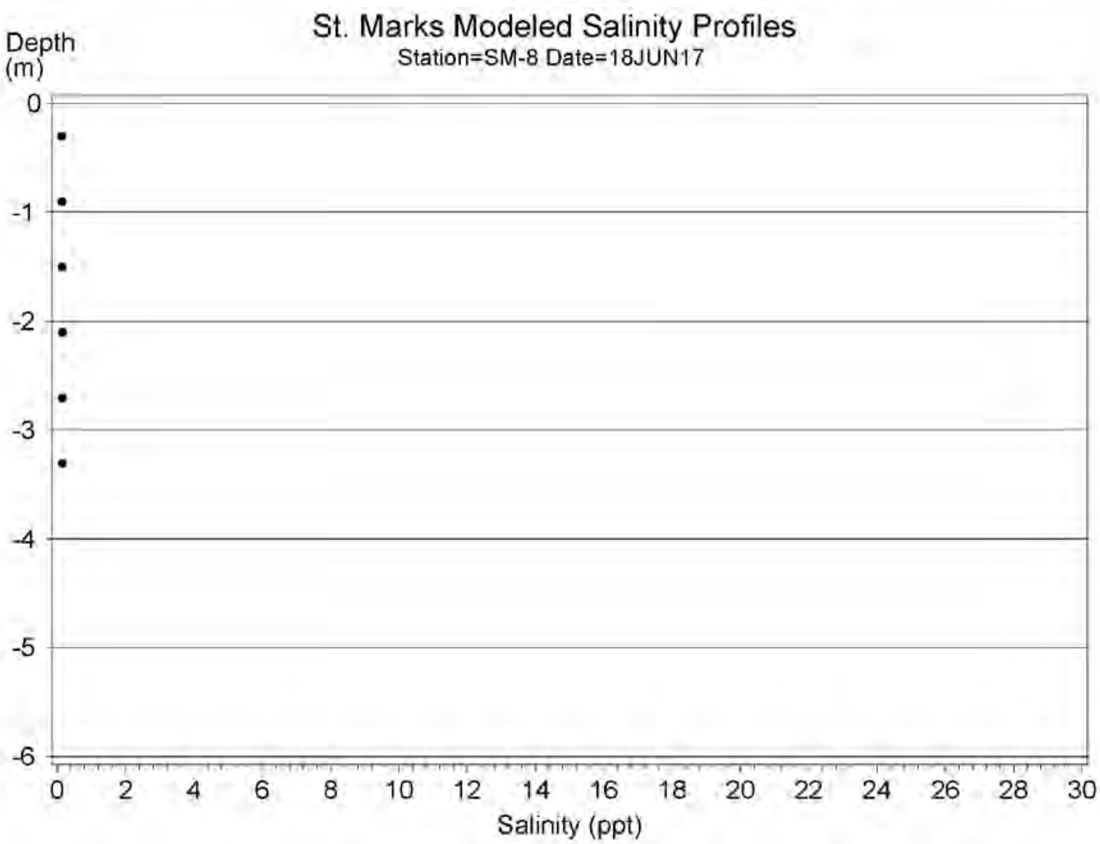
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-8 Date=18JUN17
Depth (m)
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-1
-2
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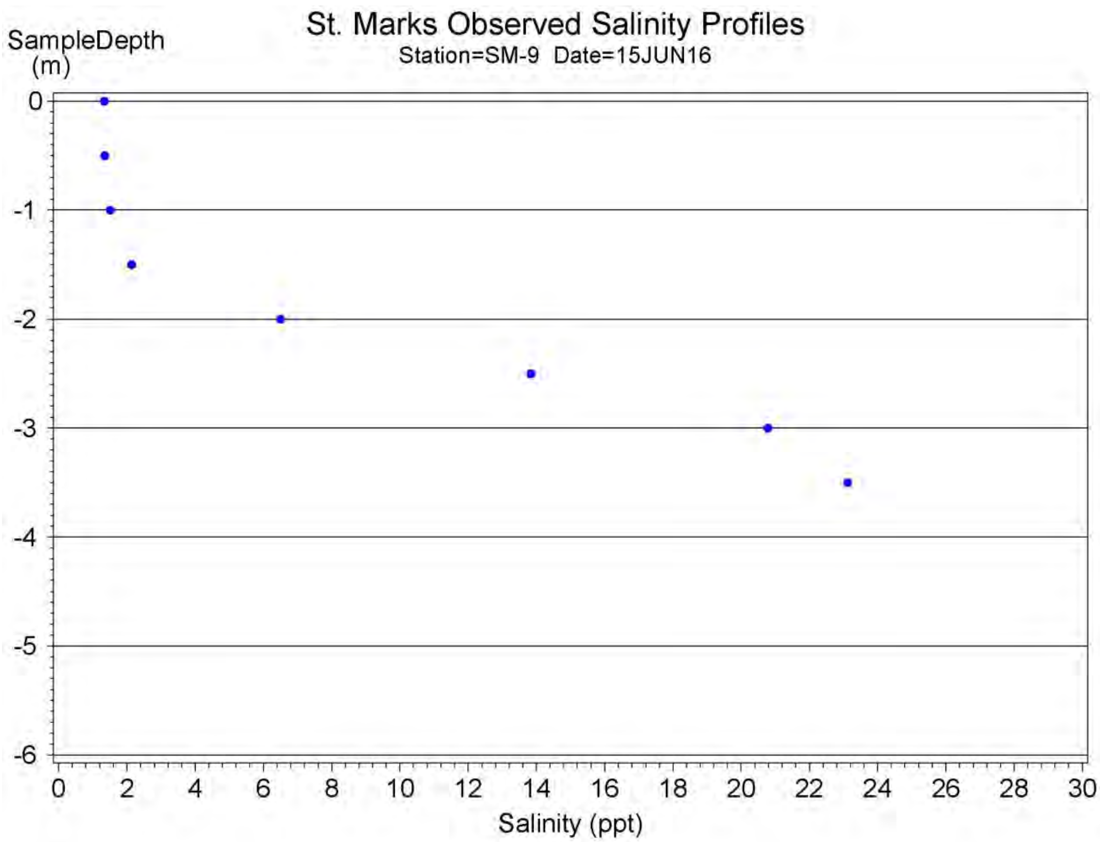
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-9 Date=15JUN16
SampleDepth (m)
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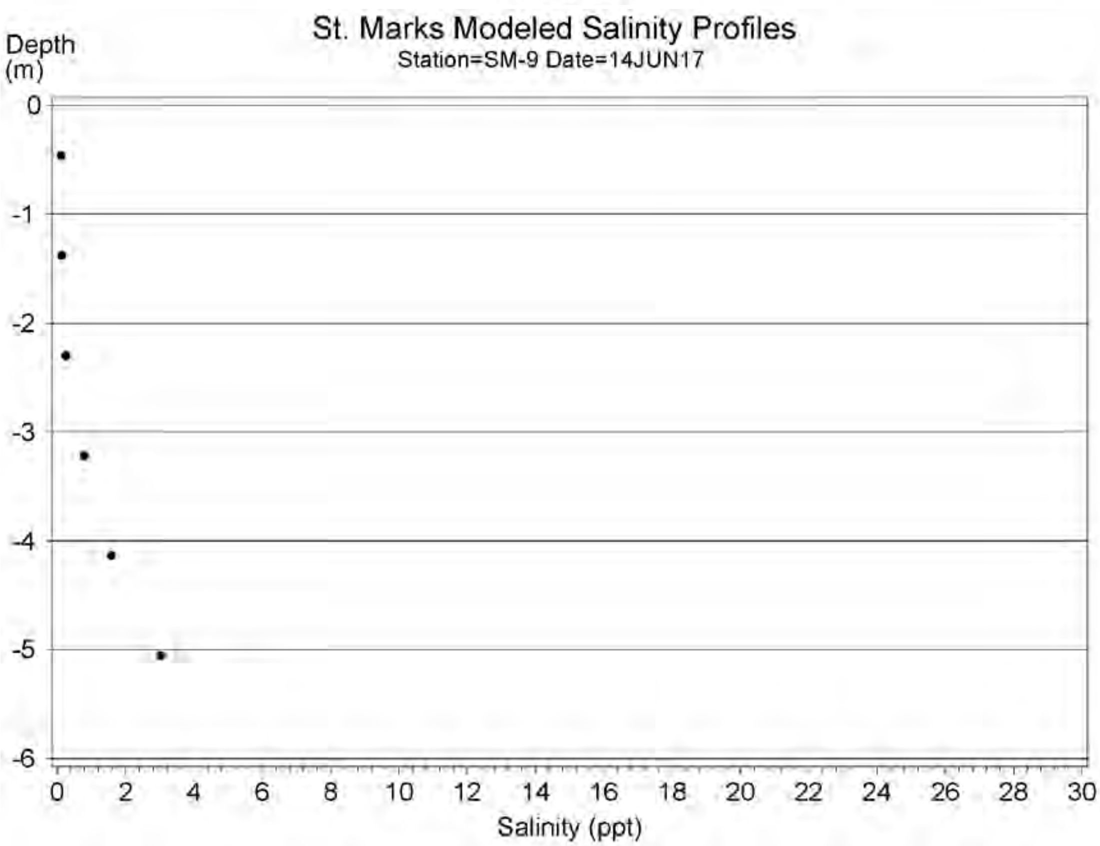
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-9 Date=14JUN17
Depth (m)
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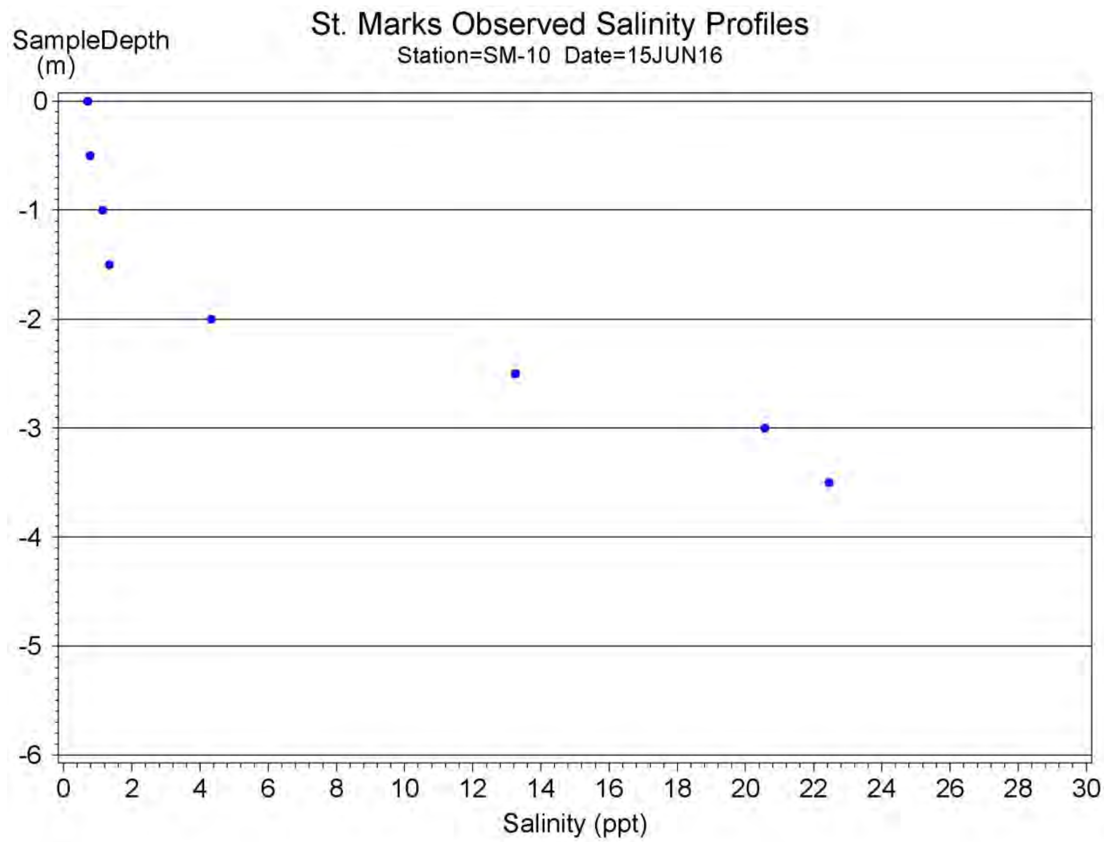
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-10 Date=15JUN16
SampleDepth (m)
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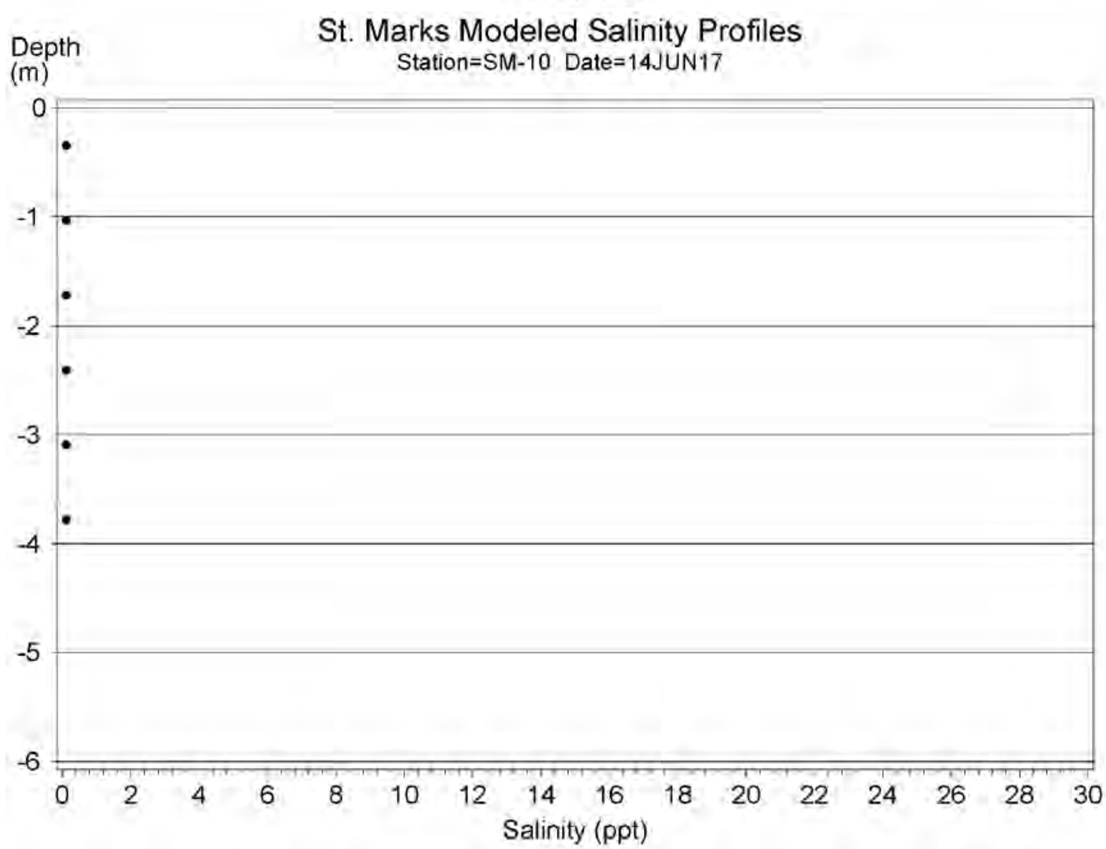
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-10 Date=14JUN17
Depth (m)
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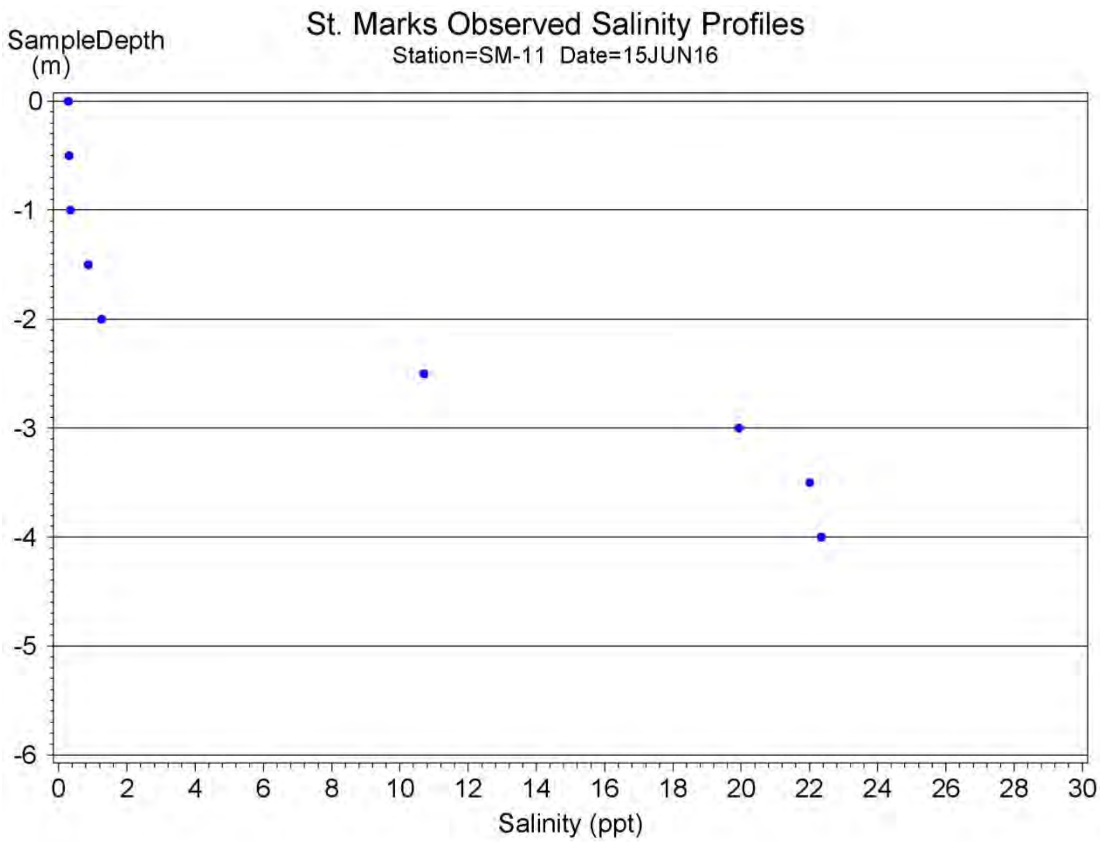
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-11 Date=15JUN16
SampleDepth
(m)
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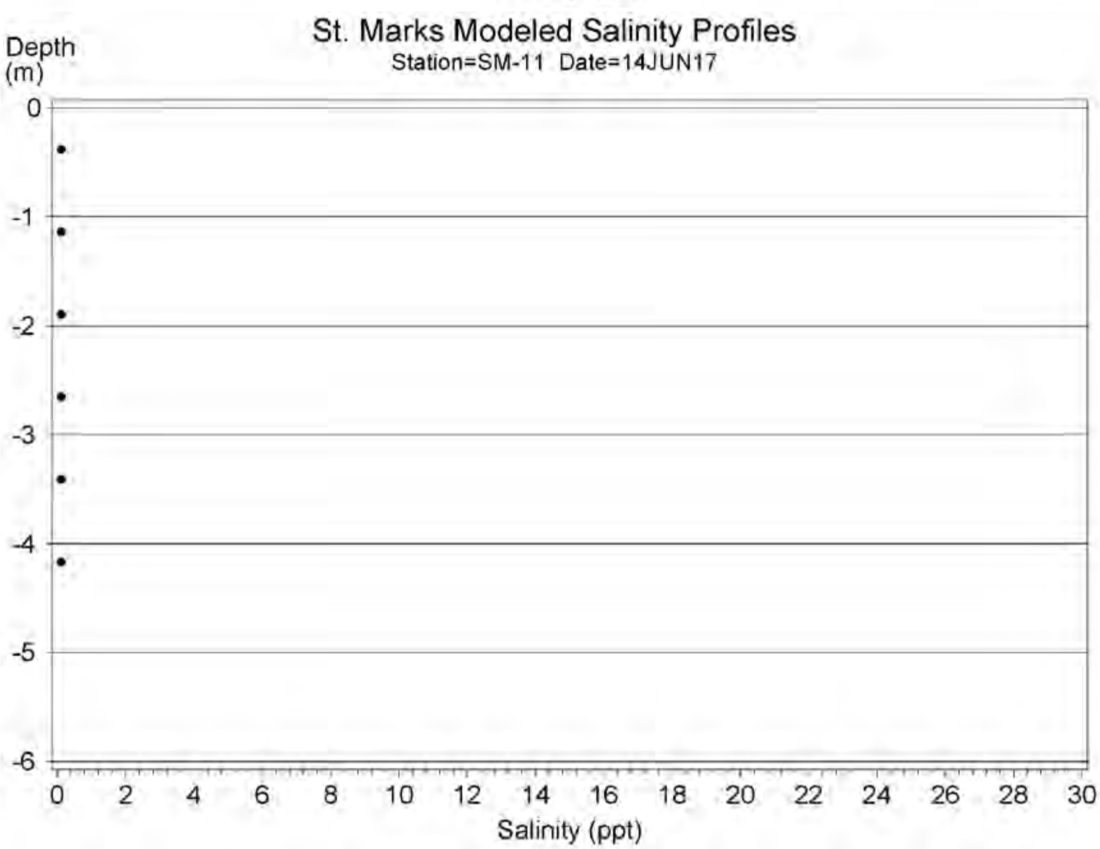
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-11 Date=14JUN17
Depth
(m)
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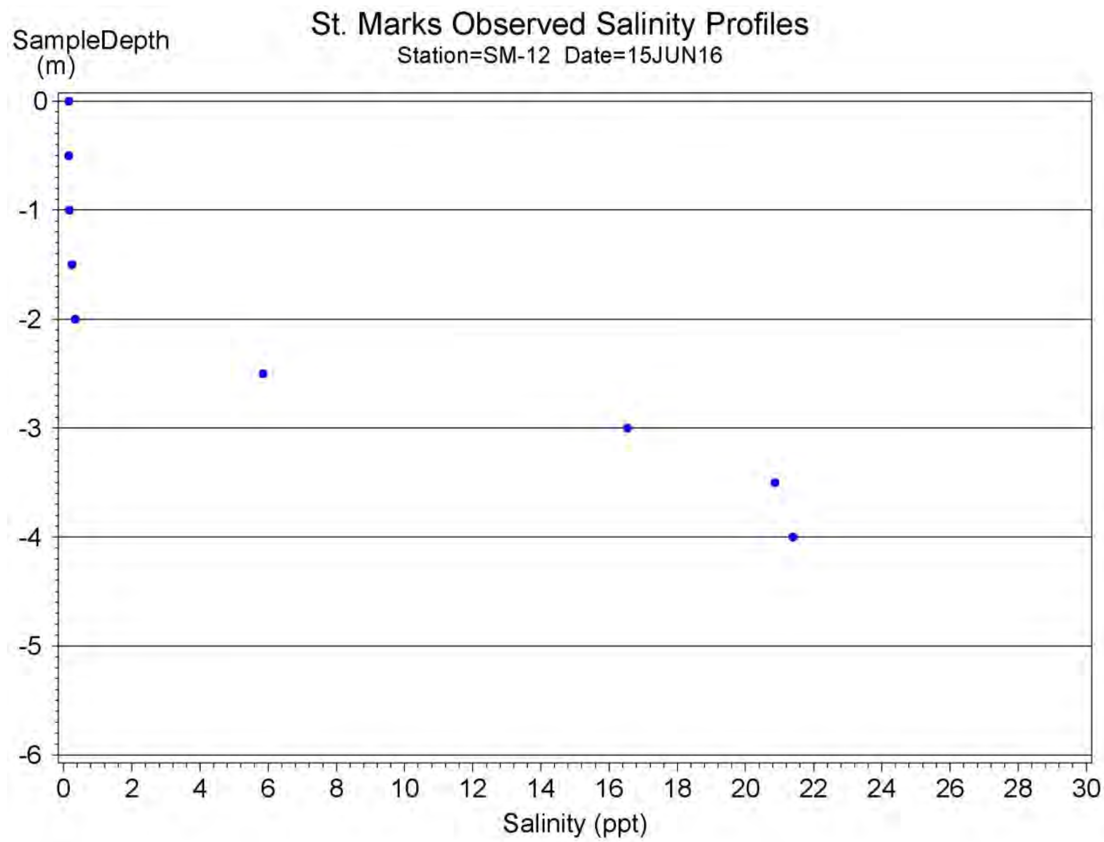
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-12 Date=15JUN16
SampleDepth (m)
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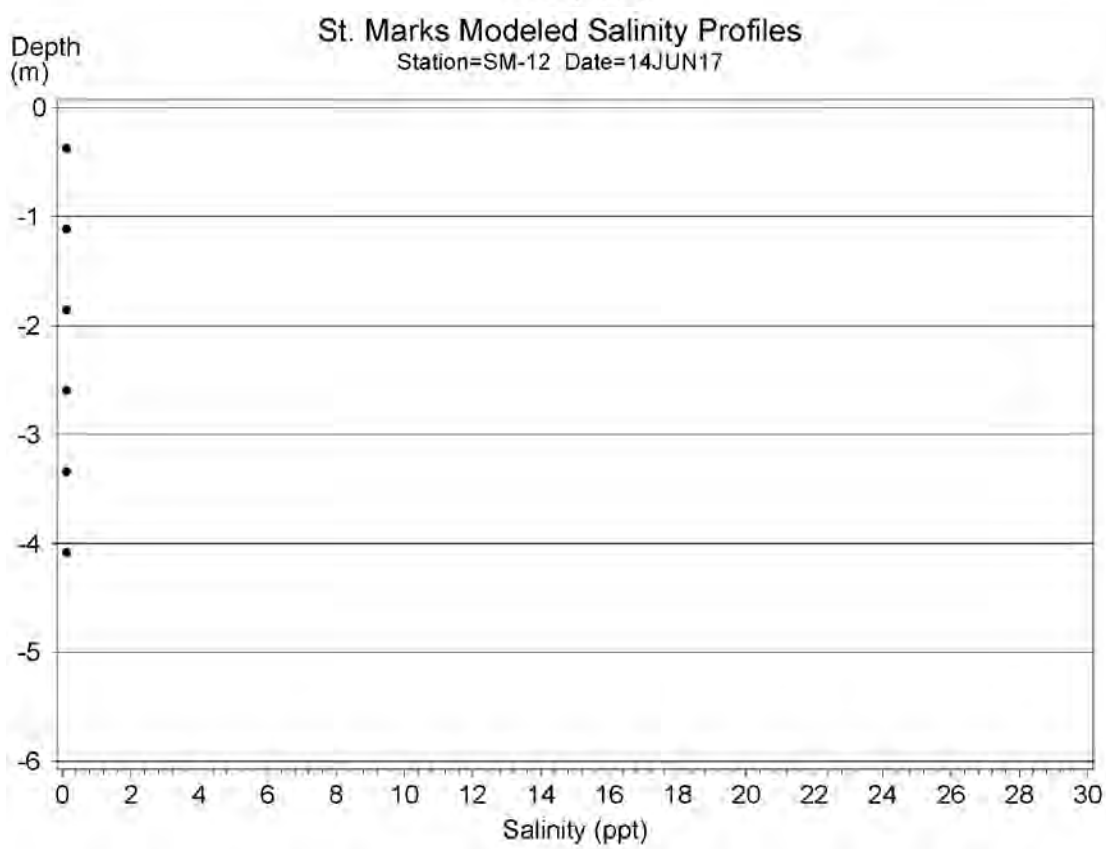
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-12 Date=14JUN17
Depth (m)
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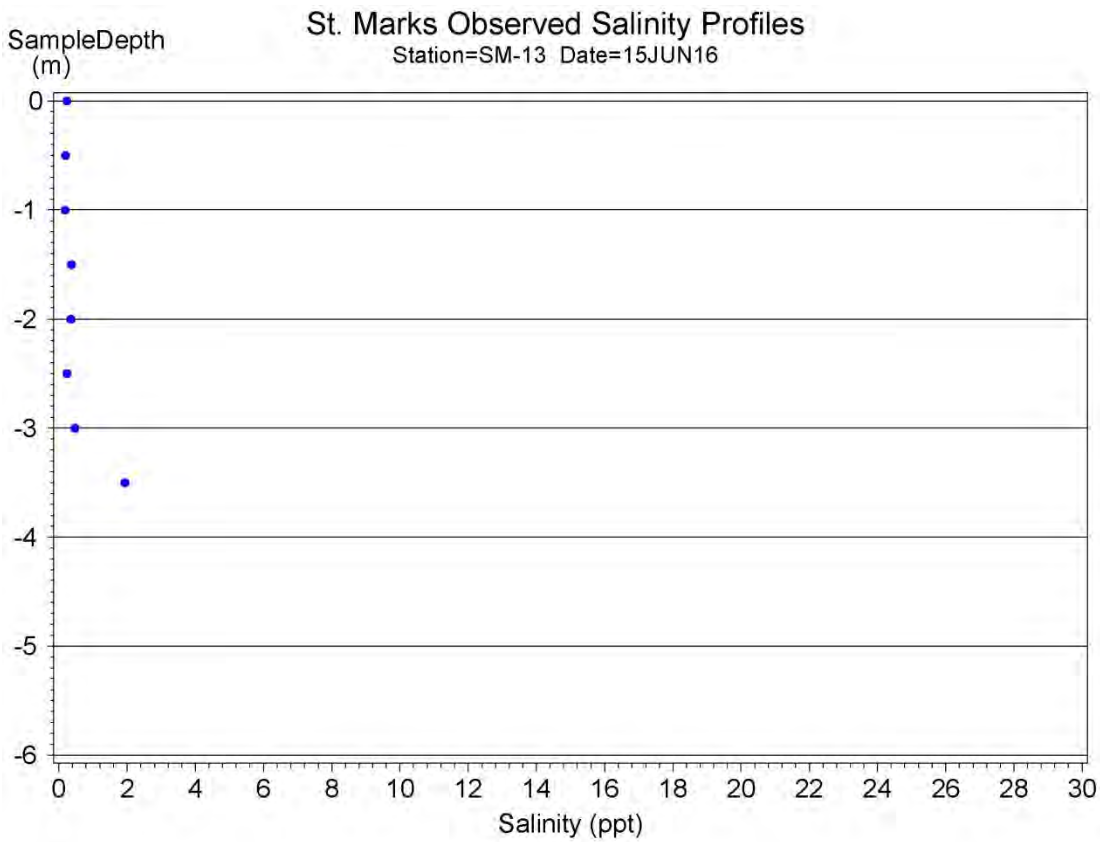
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-13 Date=15JUN16
SampleDepth (m)
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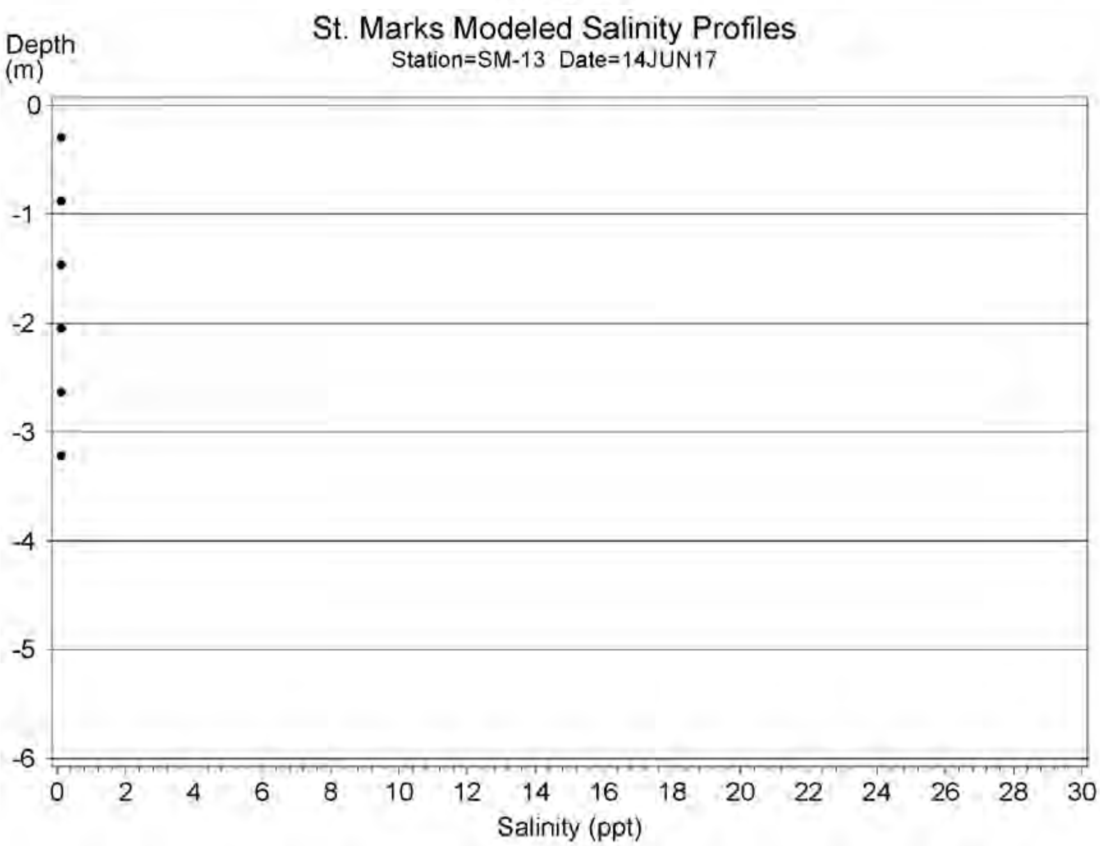
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-13 Date=14JUN17
Depth (m)
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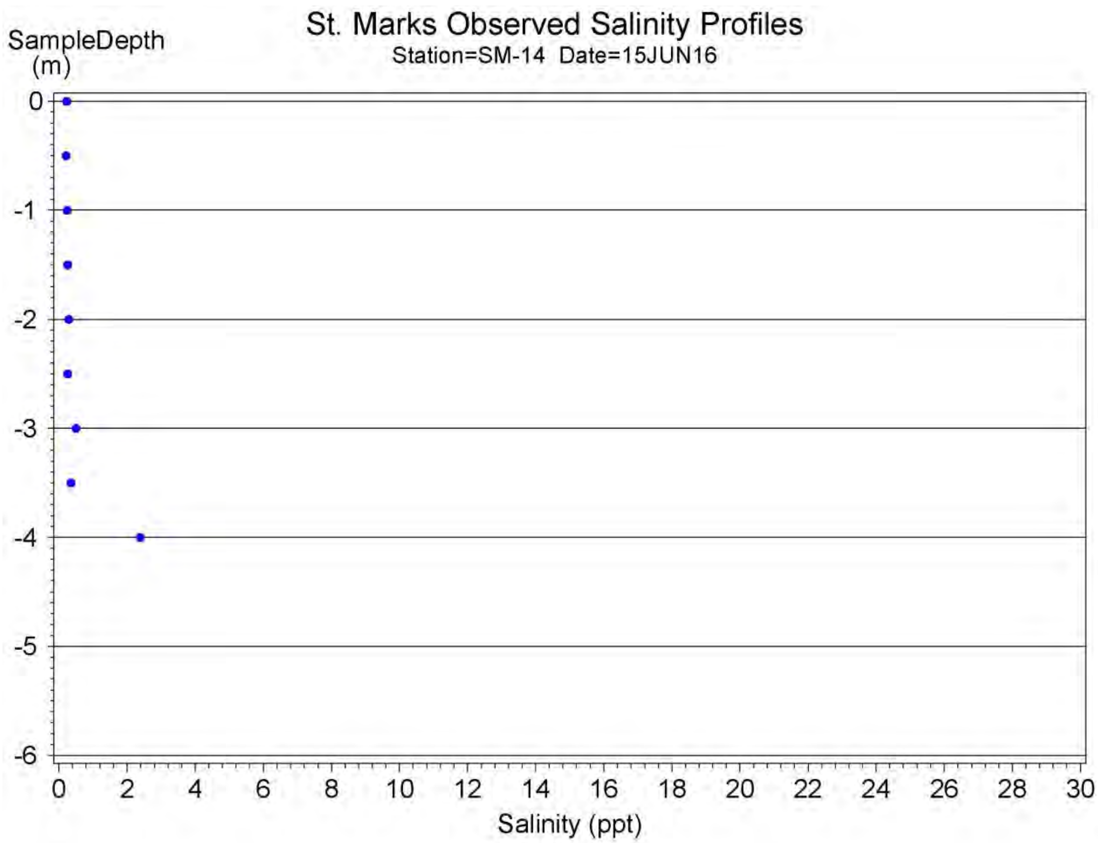
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-14 Date=15JUN16
SampleDepth (m)
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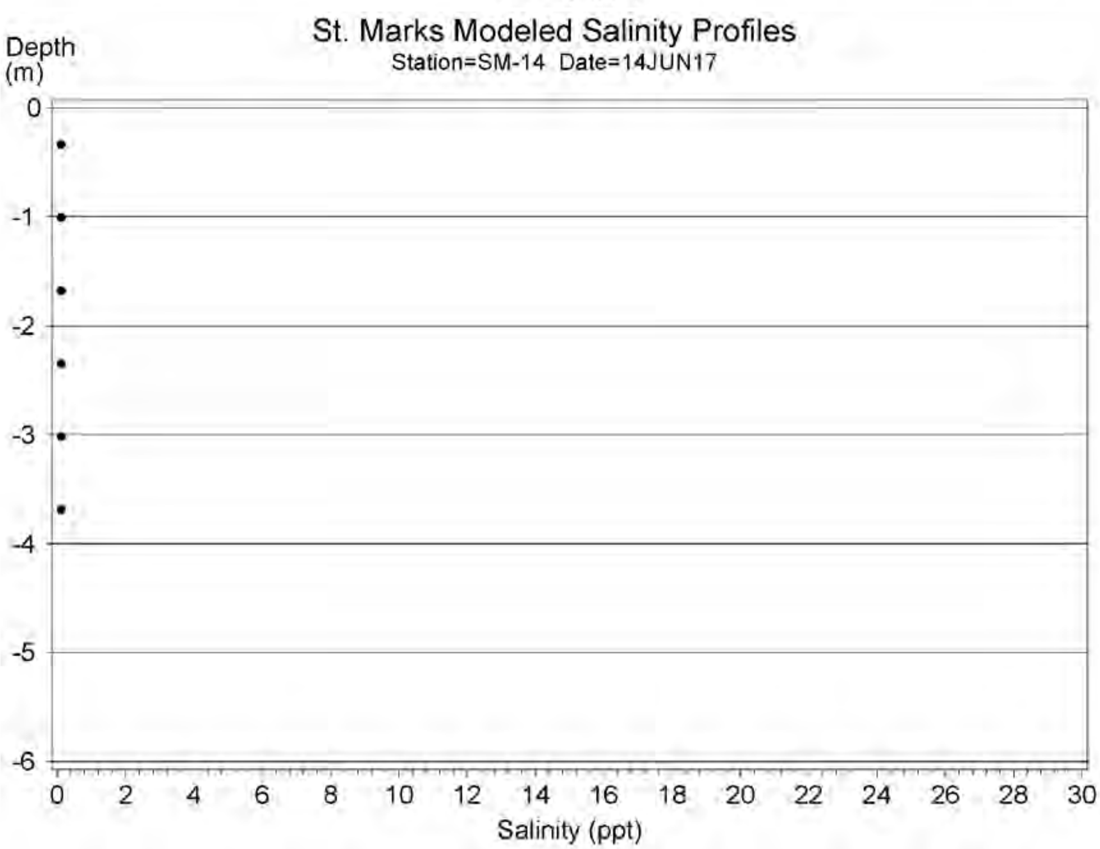
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-14 Date=14JUN17
Depth (m)
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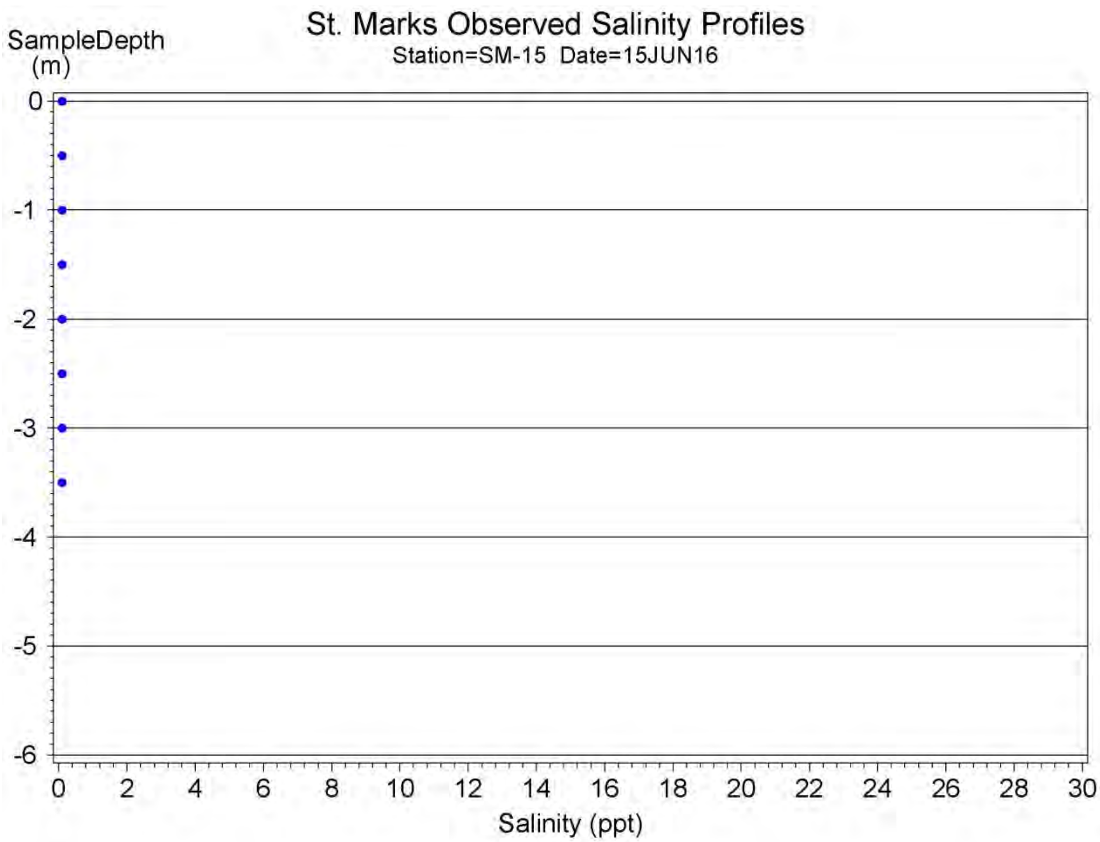
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-15 Date=15JUN16
SampleDepth (m)
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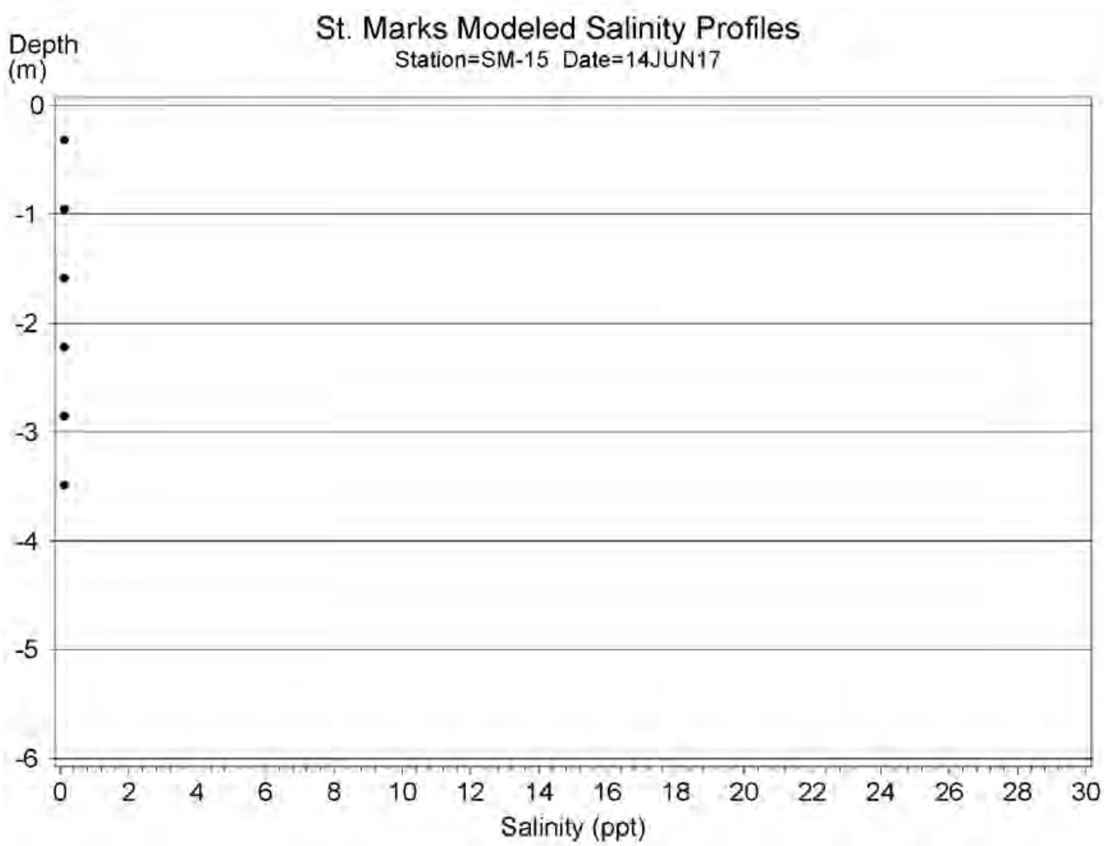
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-15 Date=14JUN17
Depth (m)
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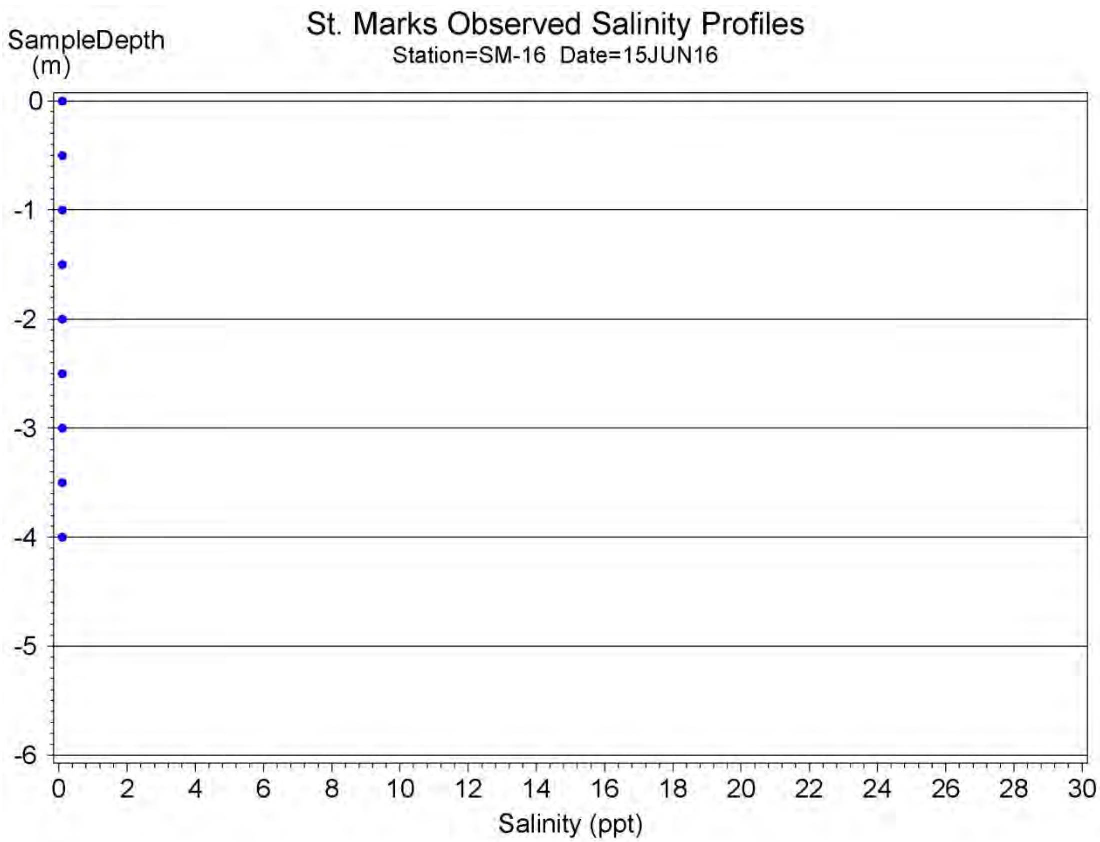
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-16 Date=15JUN16
SampleDepth (m)
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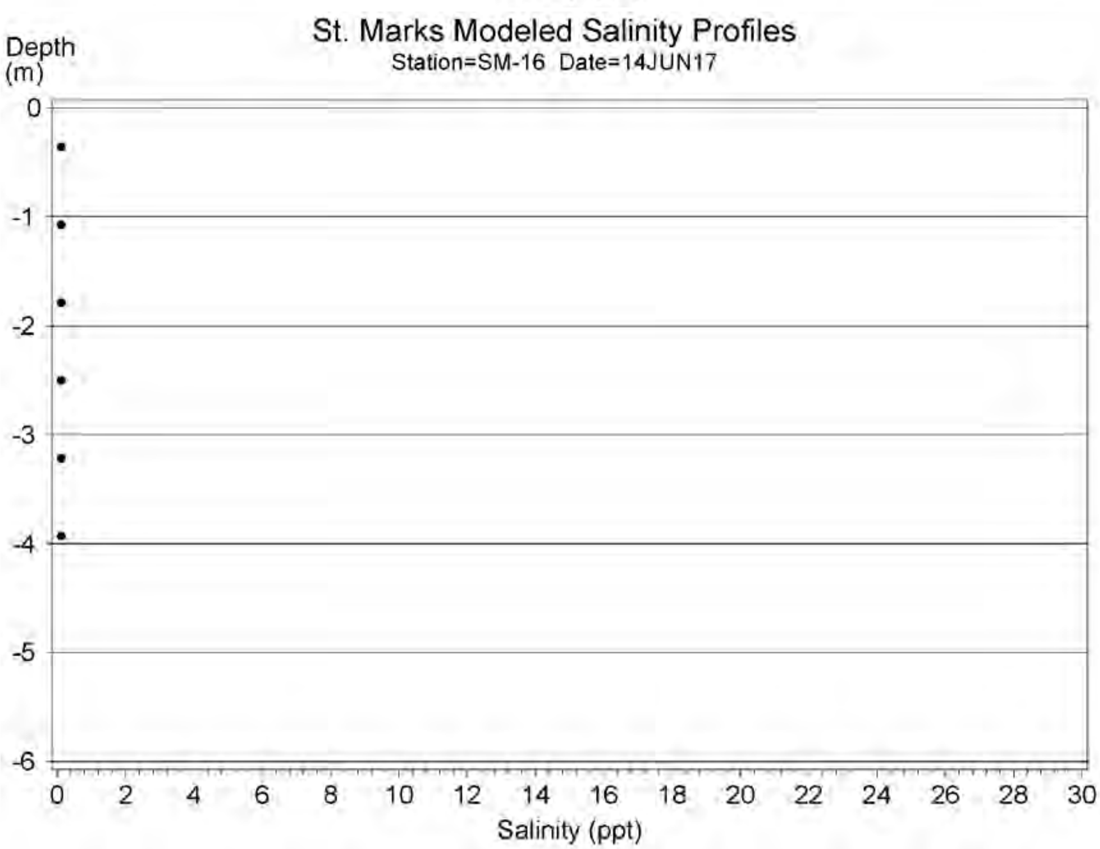
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-16 Date=14JUN17
Depth (m)
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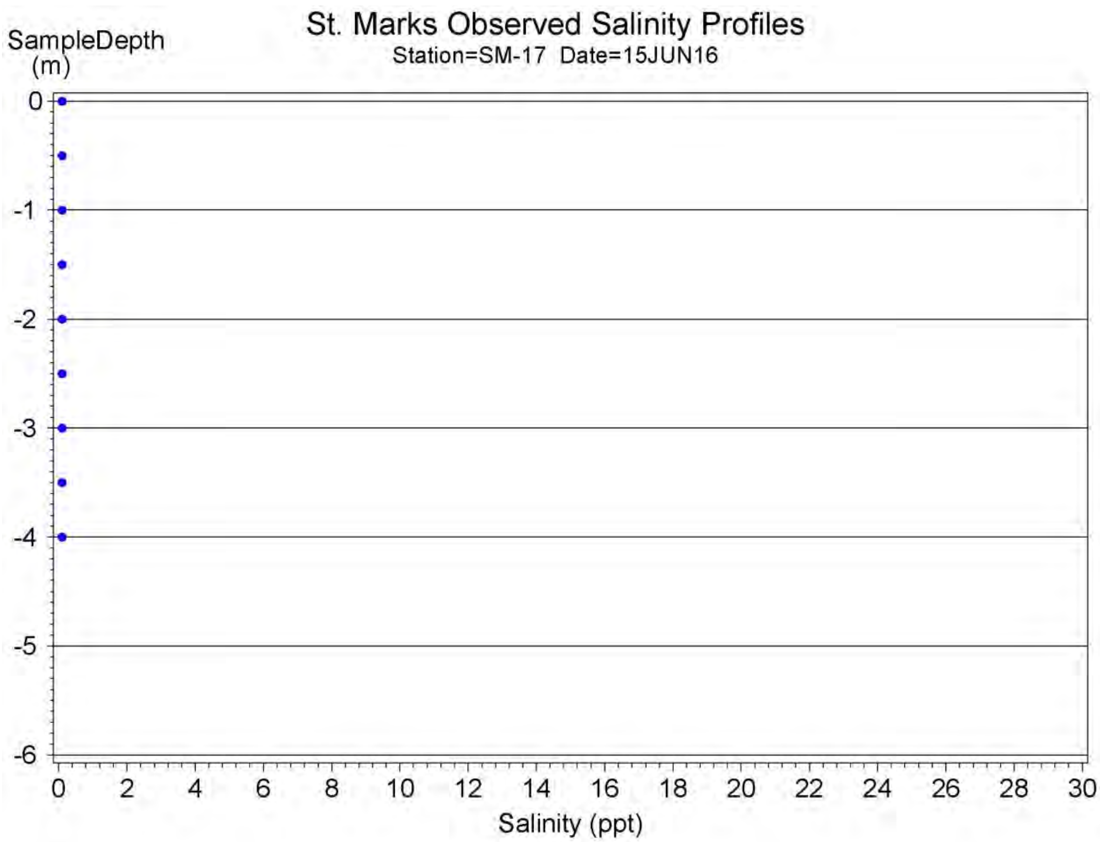
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-17 Date=15JUN16
SampleDepth (m)
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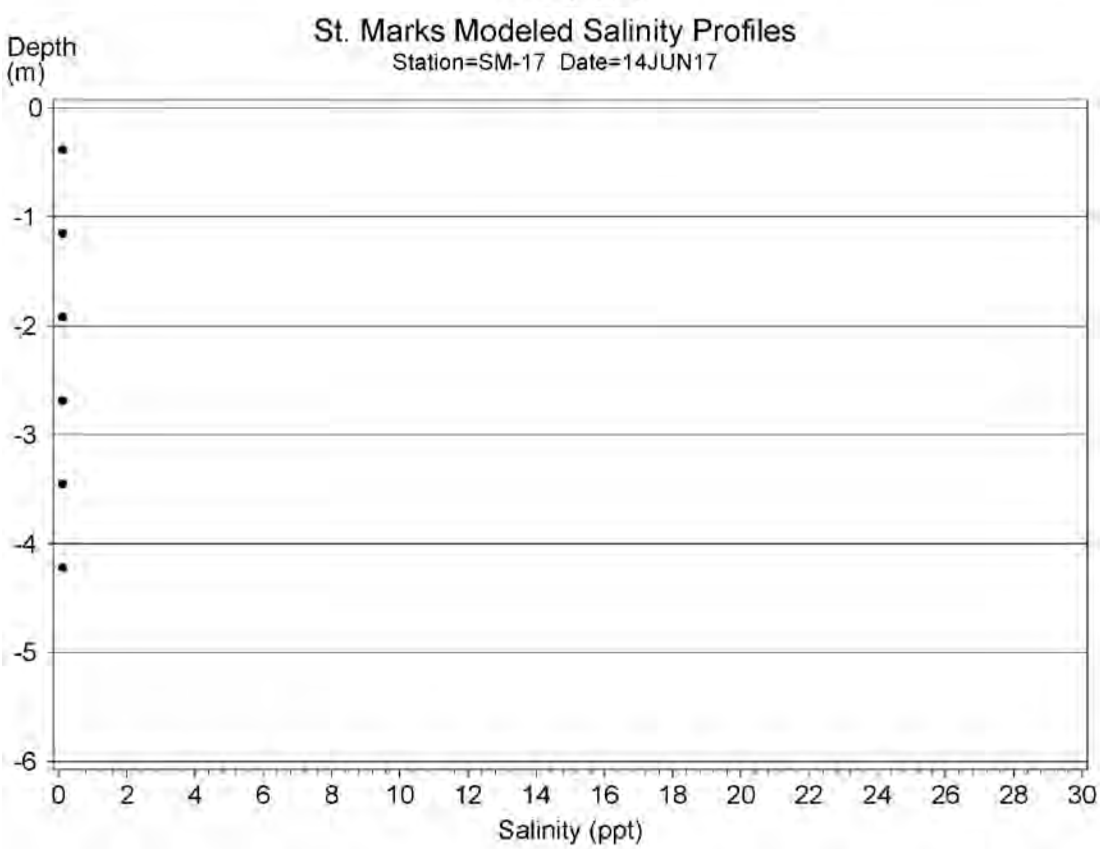
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-17 Date=14JUN17
Depth (m)
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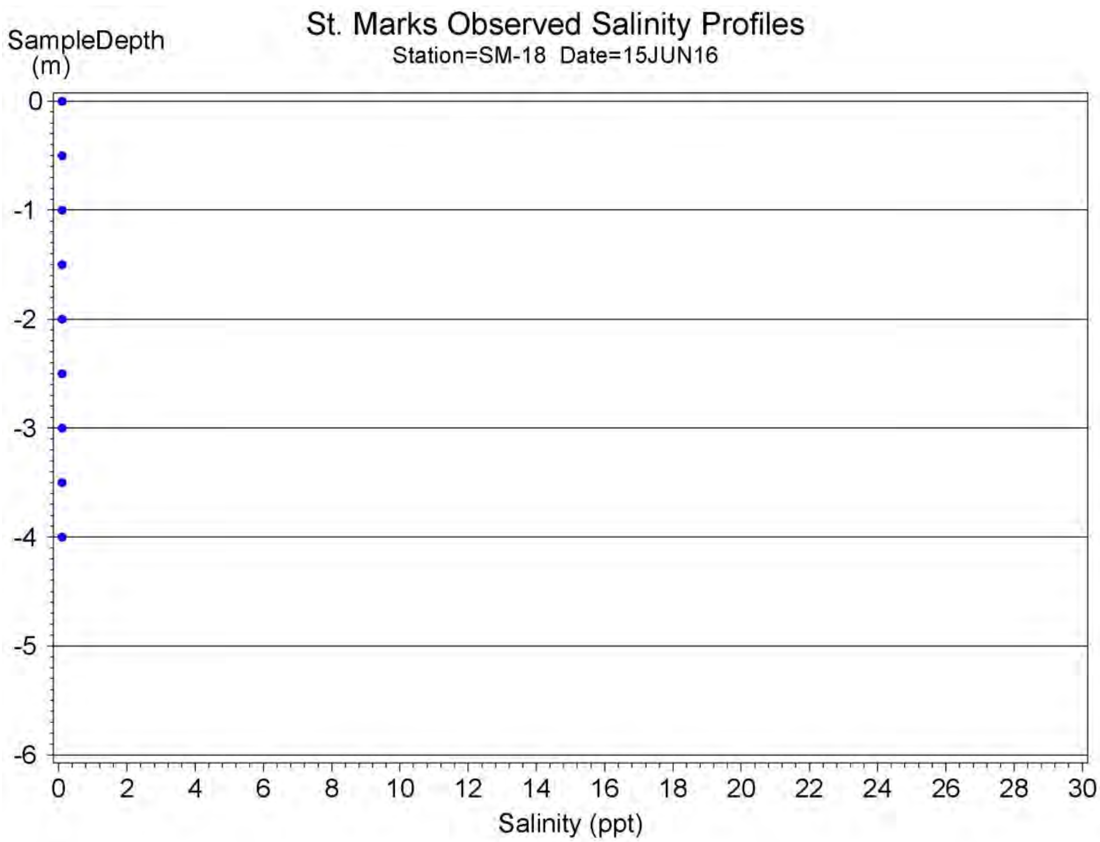
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-18 Date=15JUN16
SampleDepth (m)
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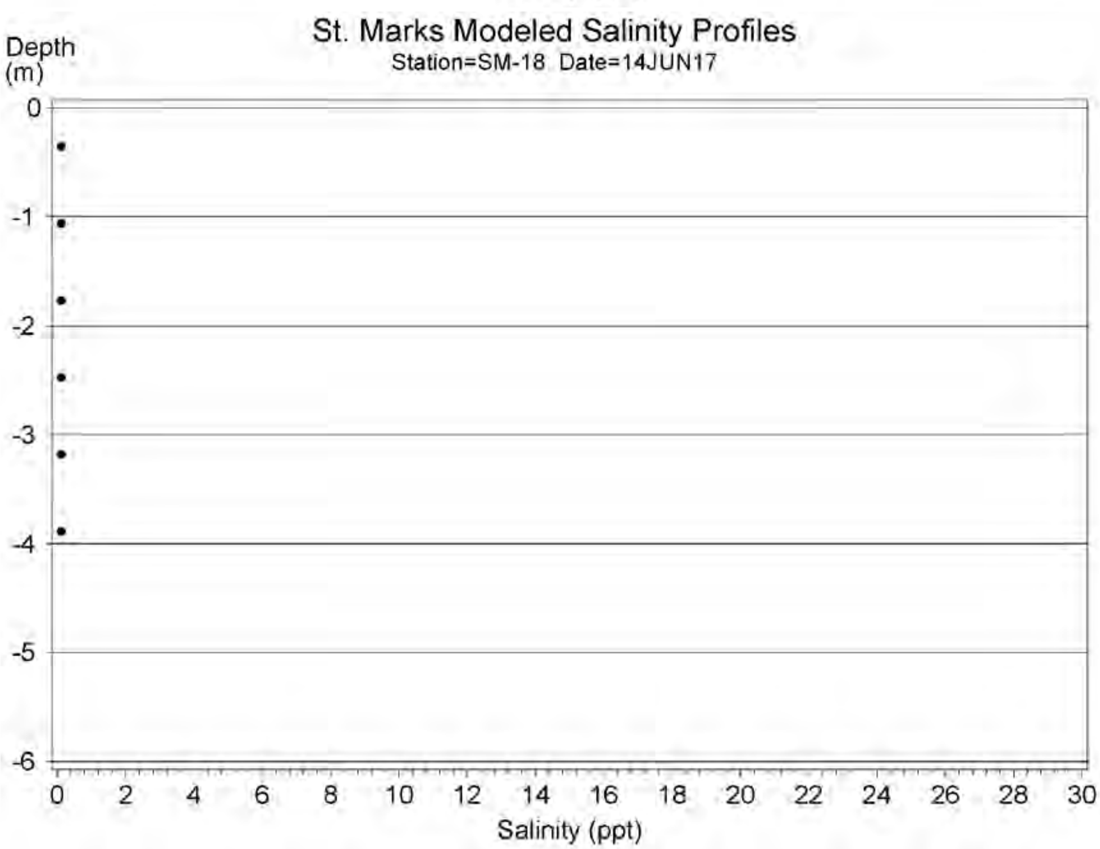
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-18 Date=14JUN17
Depth (m)
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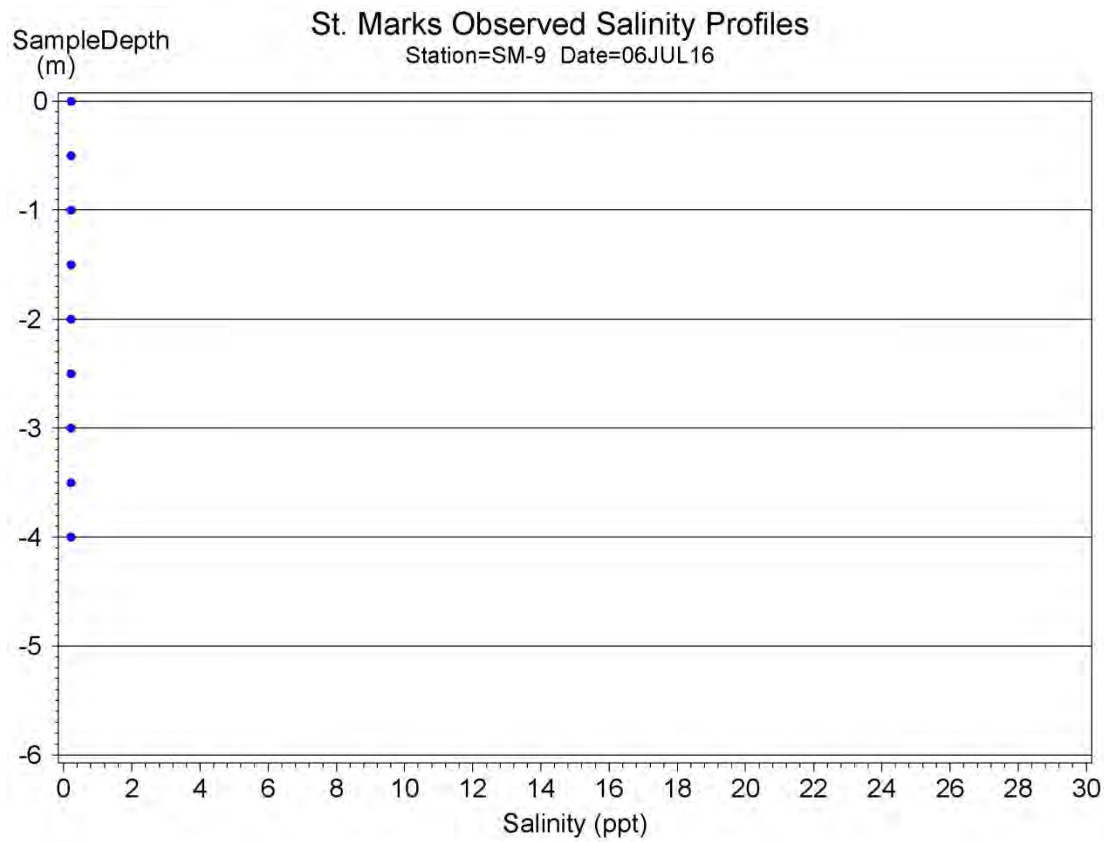
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-9 Date=06JUL16
SampleDepth (m)
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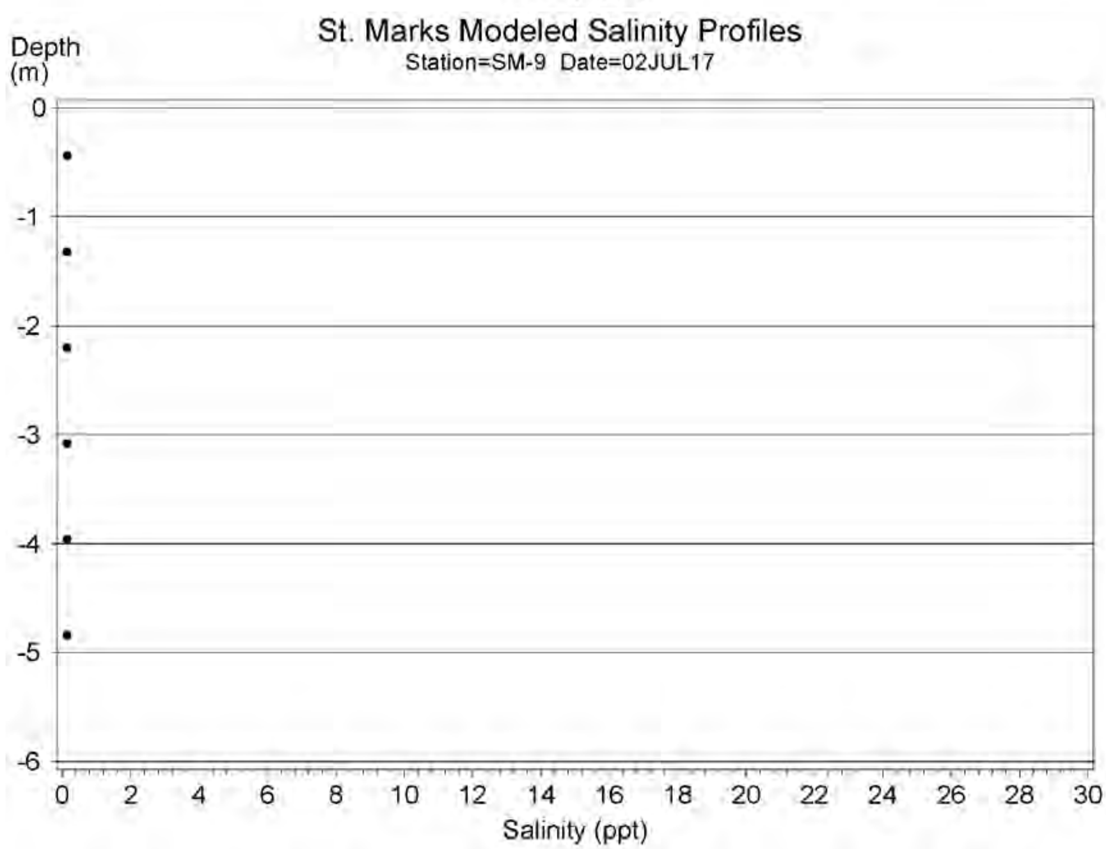
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-9 Date=02JUL17
Depth (m)
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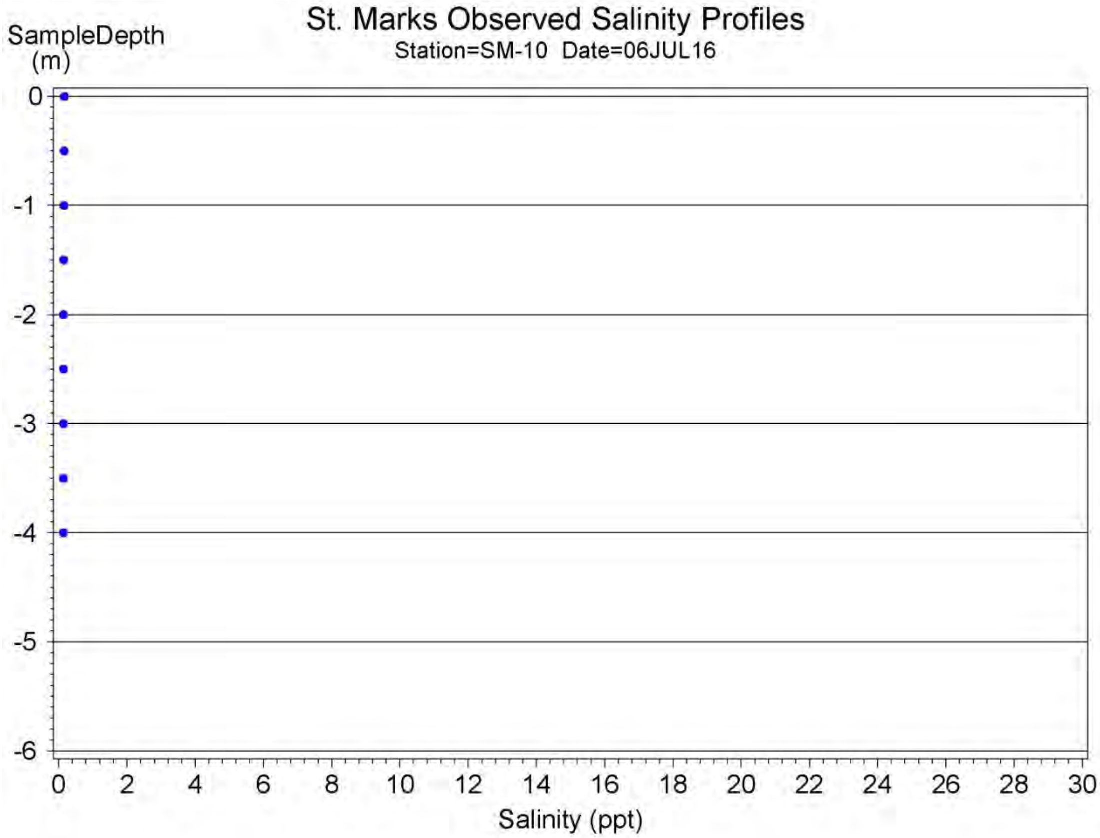
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-10 Date=06JUL16
SampleDepth (m)
0
-1
-2
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-4
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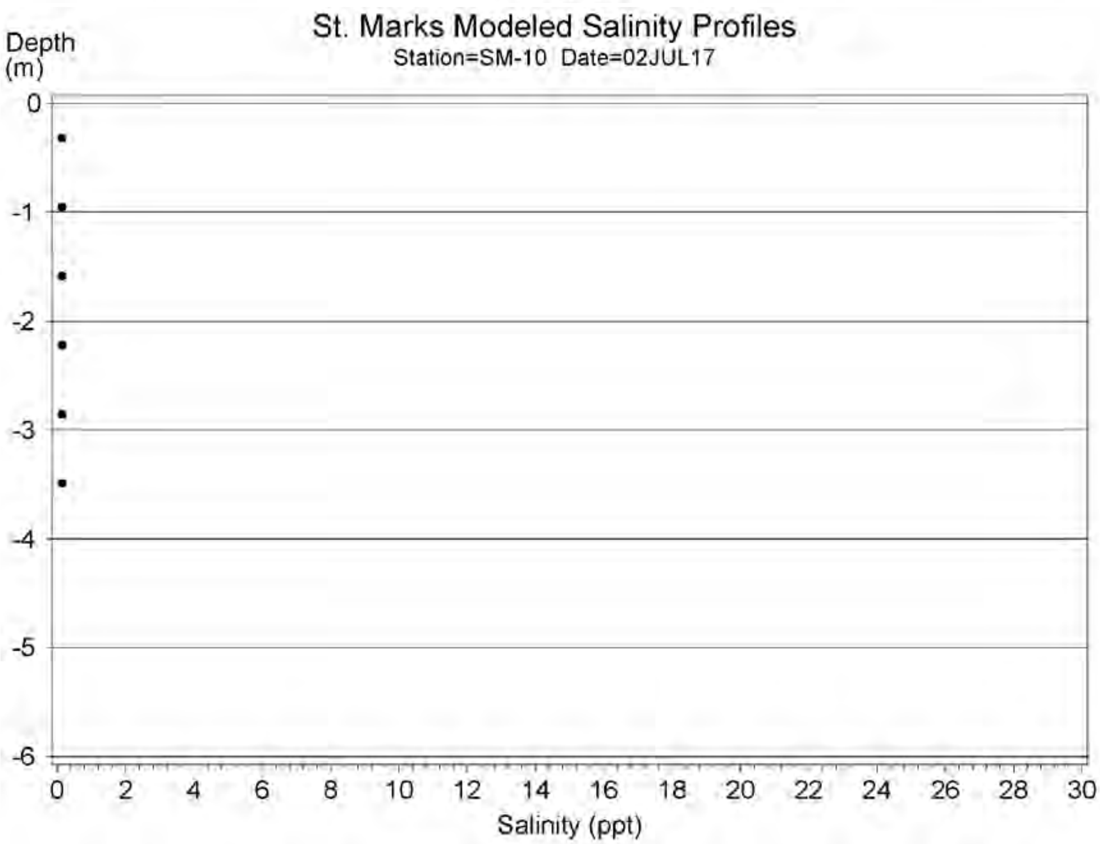
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-10 Date=02JUL17
Depth (m)
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-1
-2
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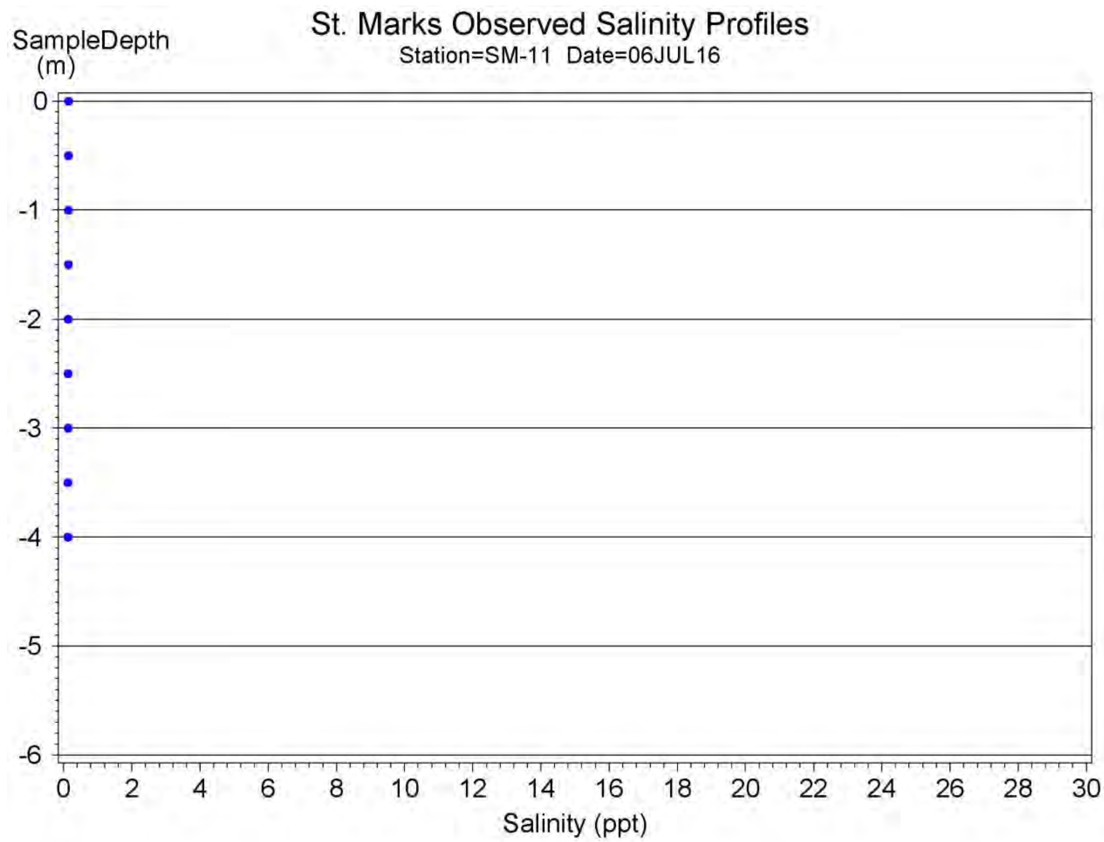
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-11 Date=06JUL16
SampleDepth (m)
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-1
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-3
-4
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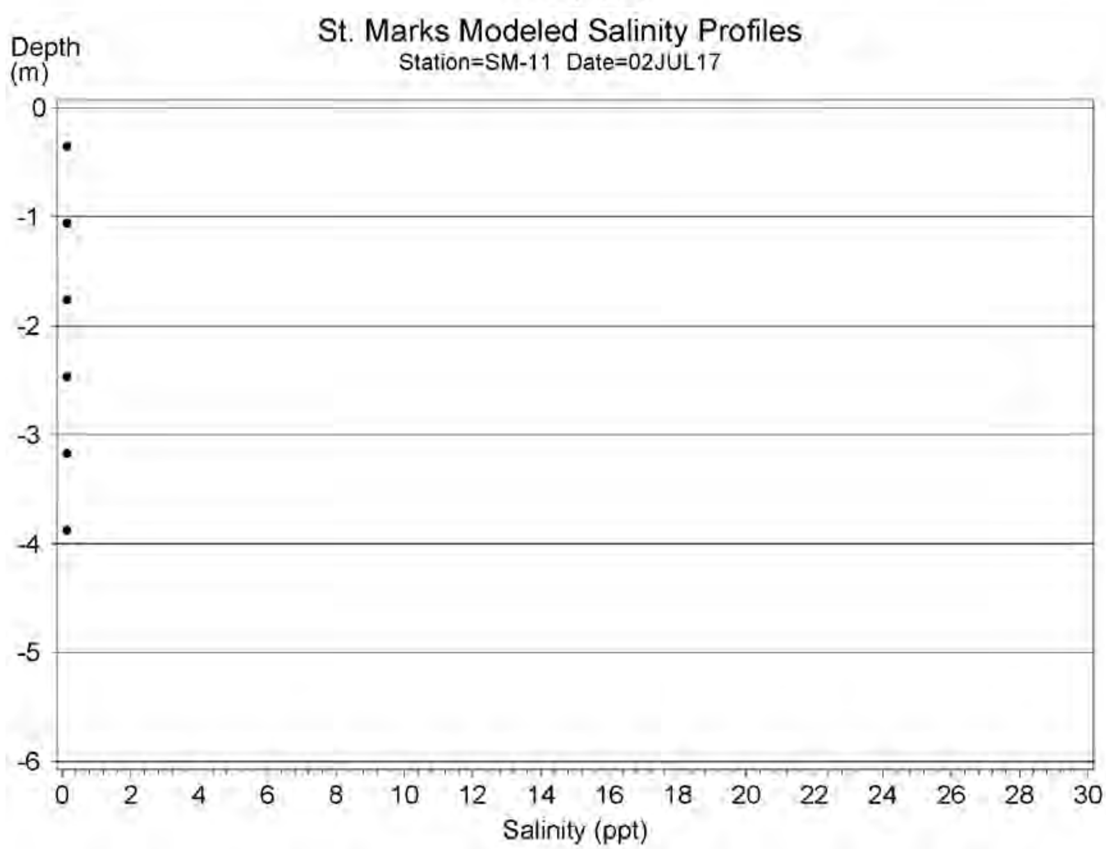
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-11 Date=02JUL17
Depth (m)
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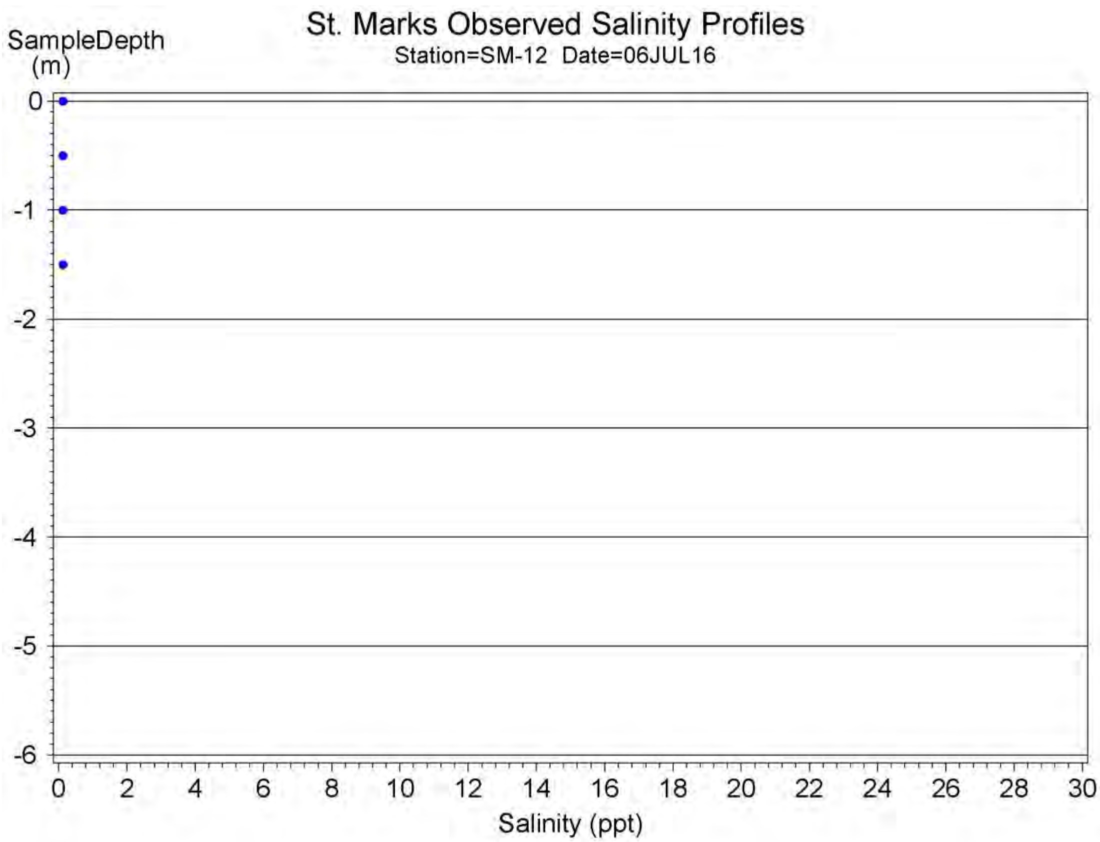
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-12 Date=06JUL16
SampleDepth (m)
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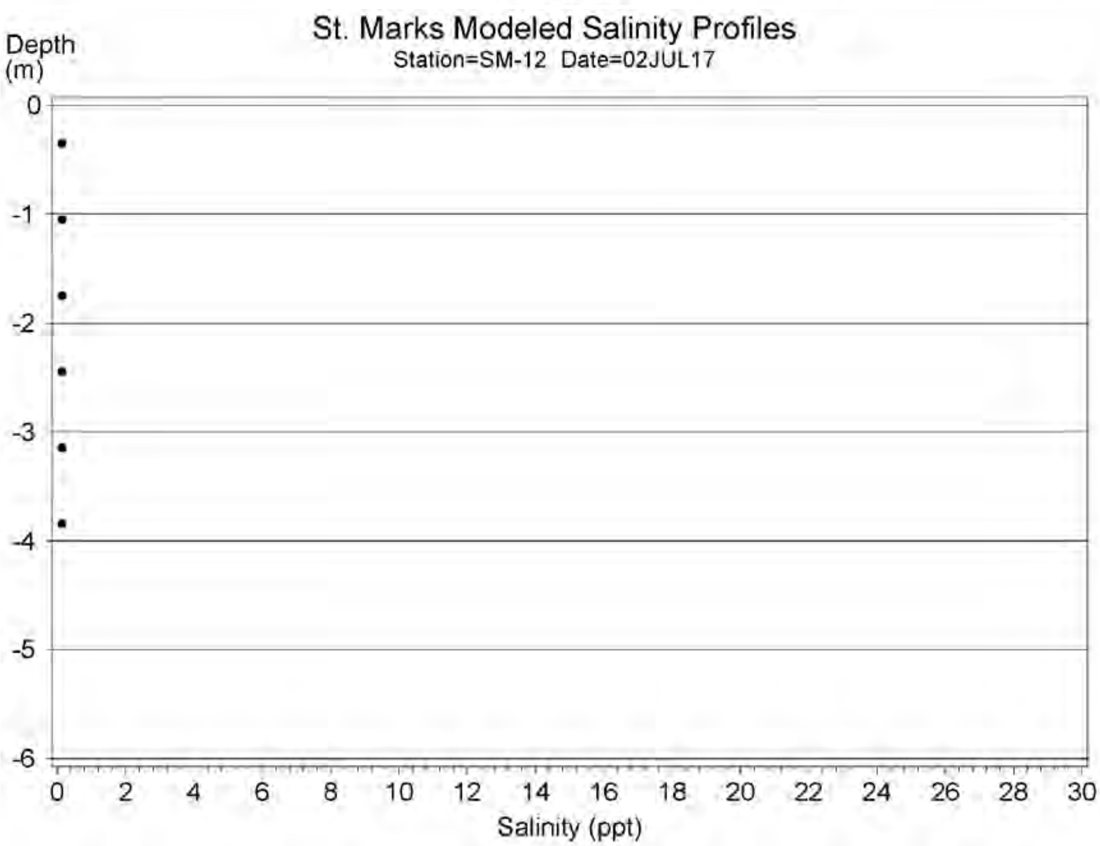
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-12 Date=02JUL17
Depth (m)
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-2
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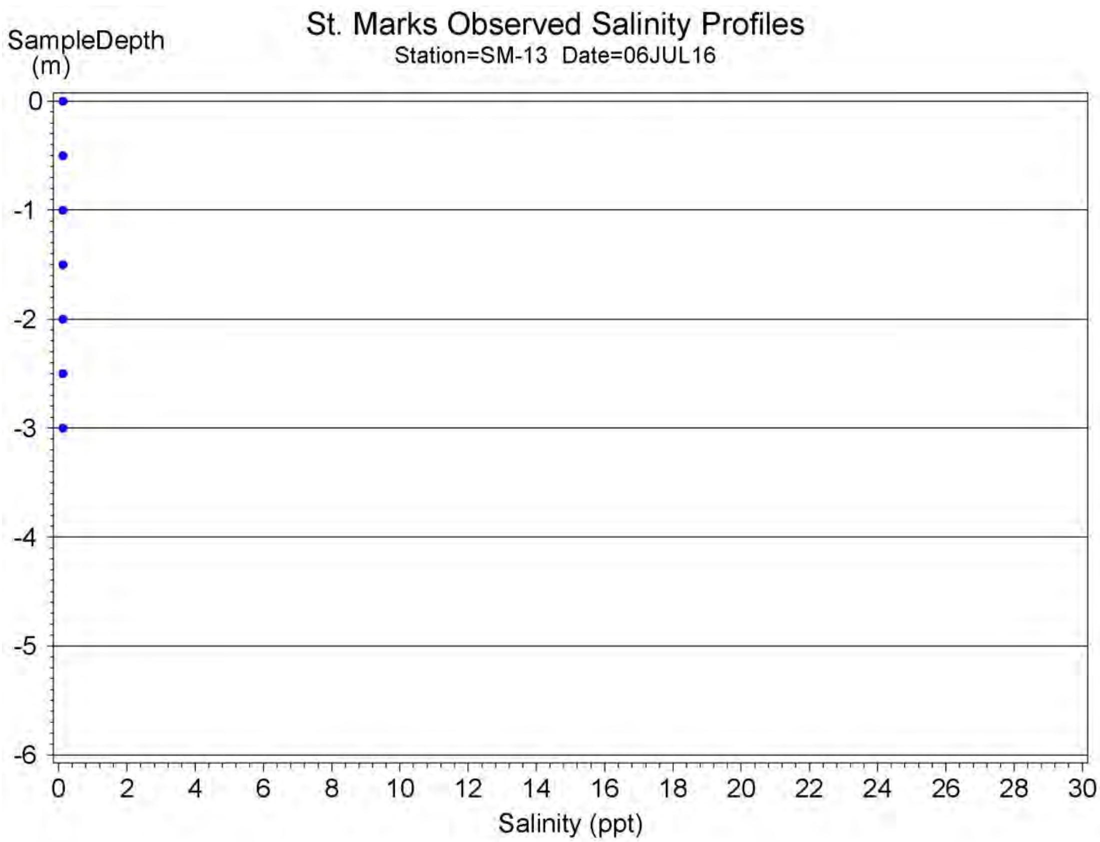
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-13 Date=06JUL16
SampleDepth (m)
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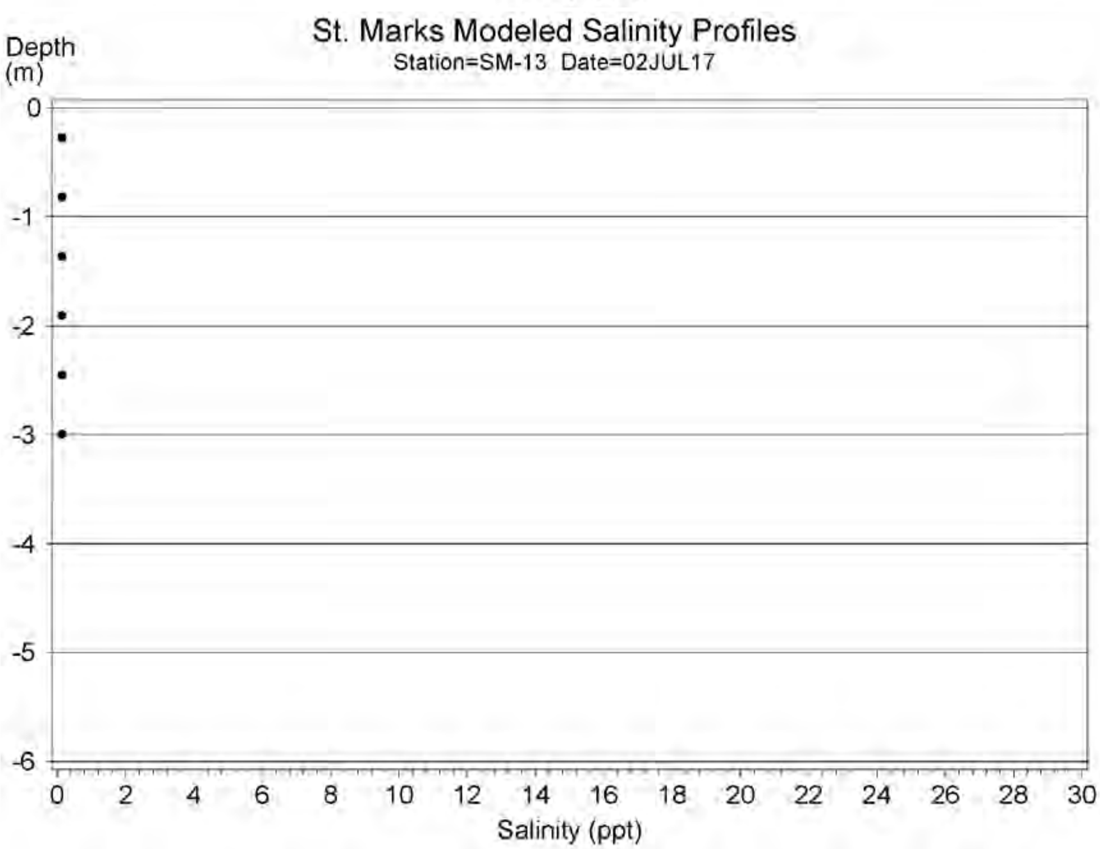
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-13 Date=02JUL17
Depth (m)
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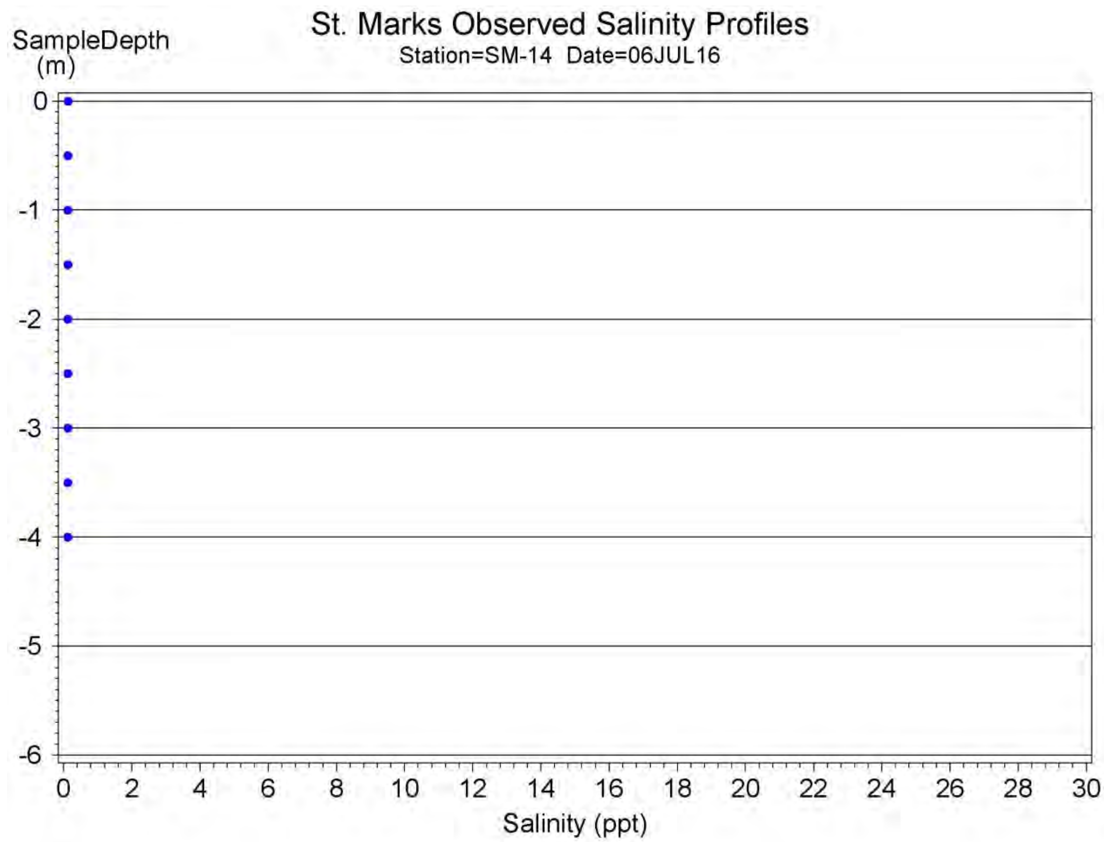
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-14 Date=06JUL16
SampleDepth (m)
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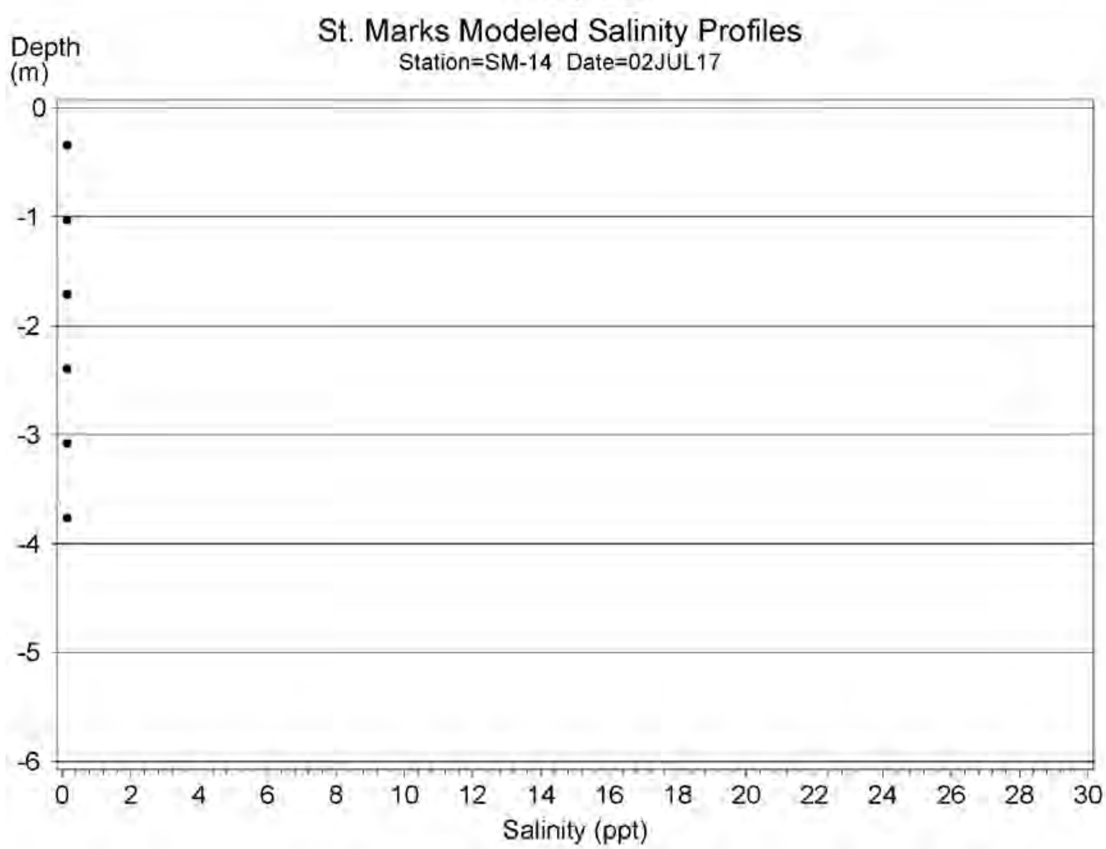
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-14 Date=02JUL17
Depth (m)
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-2
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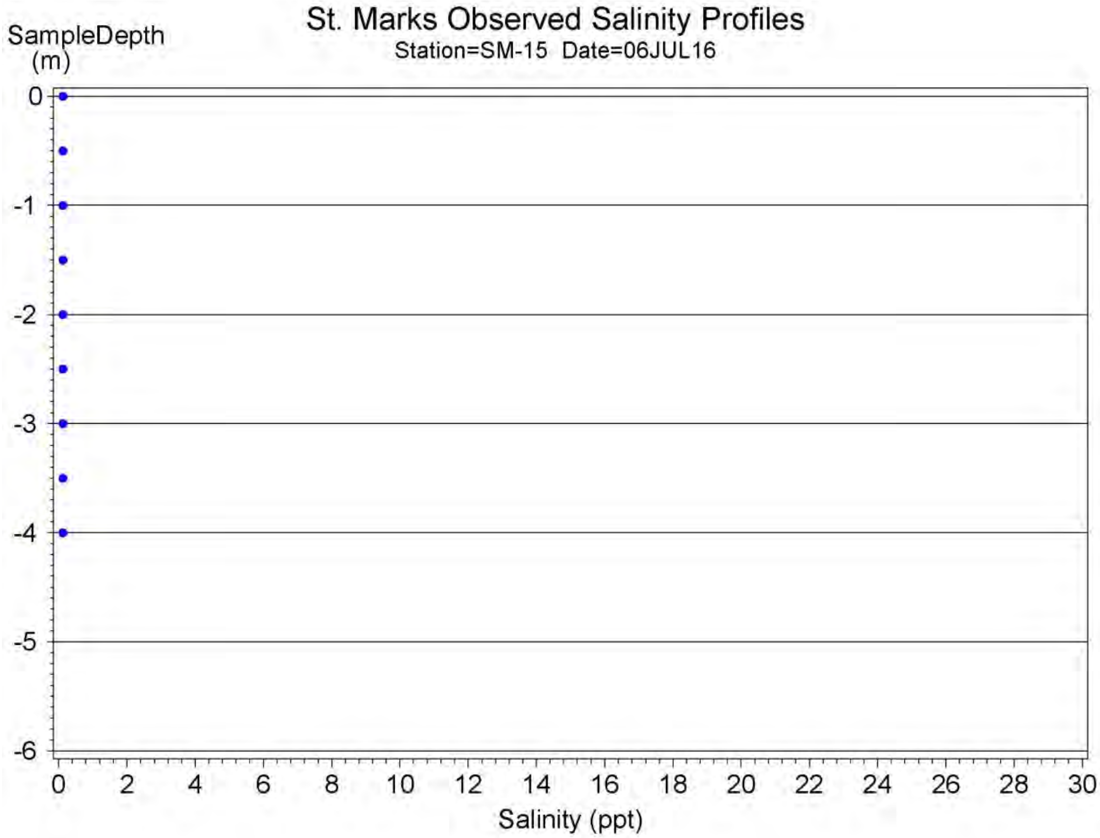
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-15 Date=06JUL16
SampleDepth (m)
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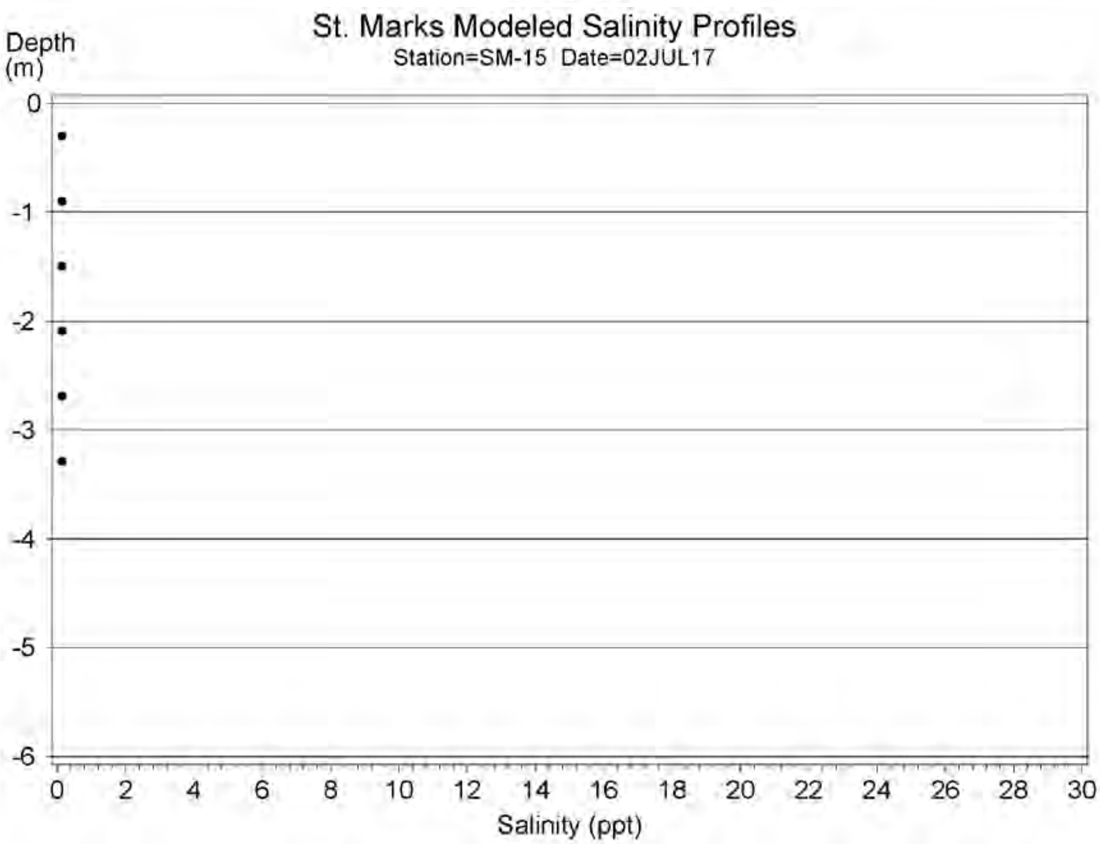
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-15 Date=02JUL17
Depth (m)
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-2
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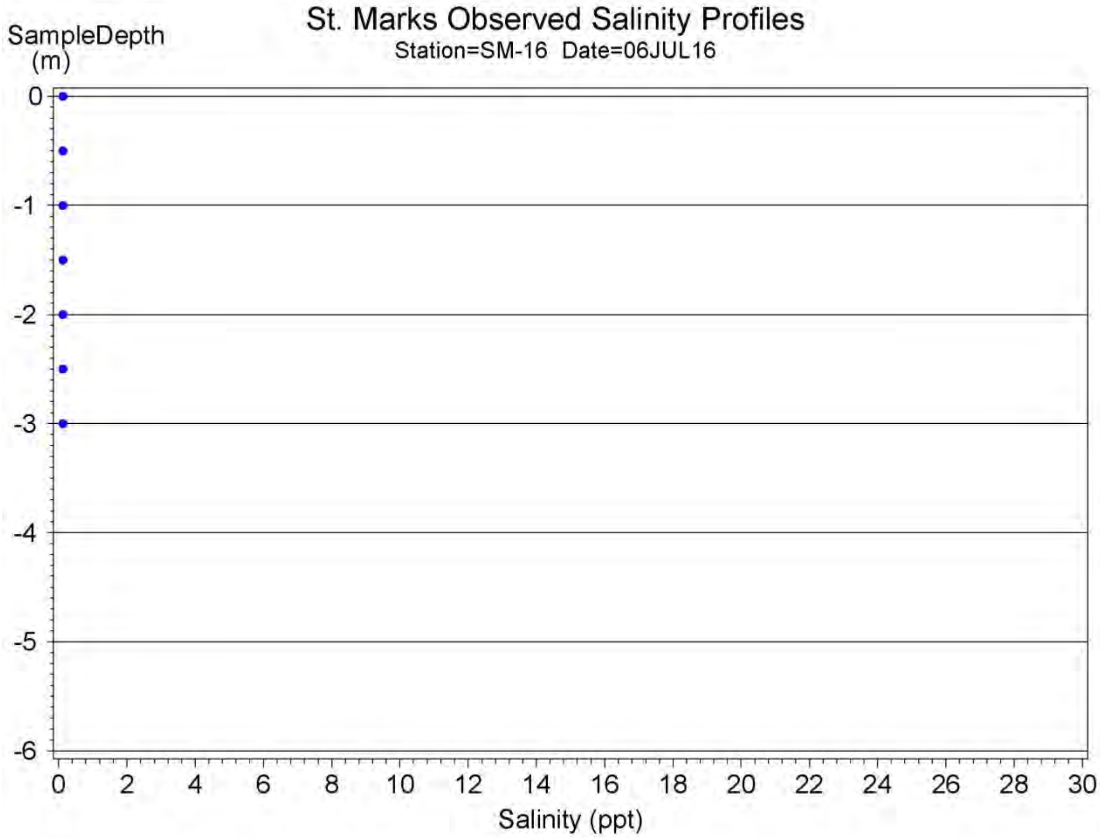
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-16 Date=06JUL16
SampleDepth (m)
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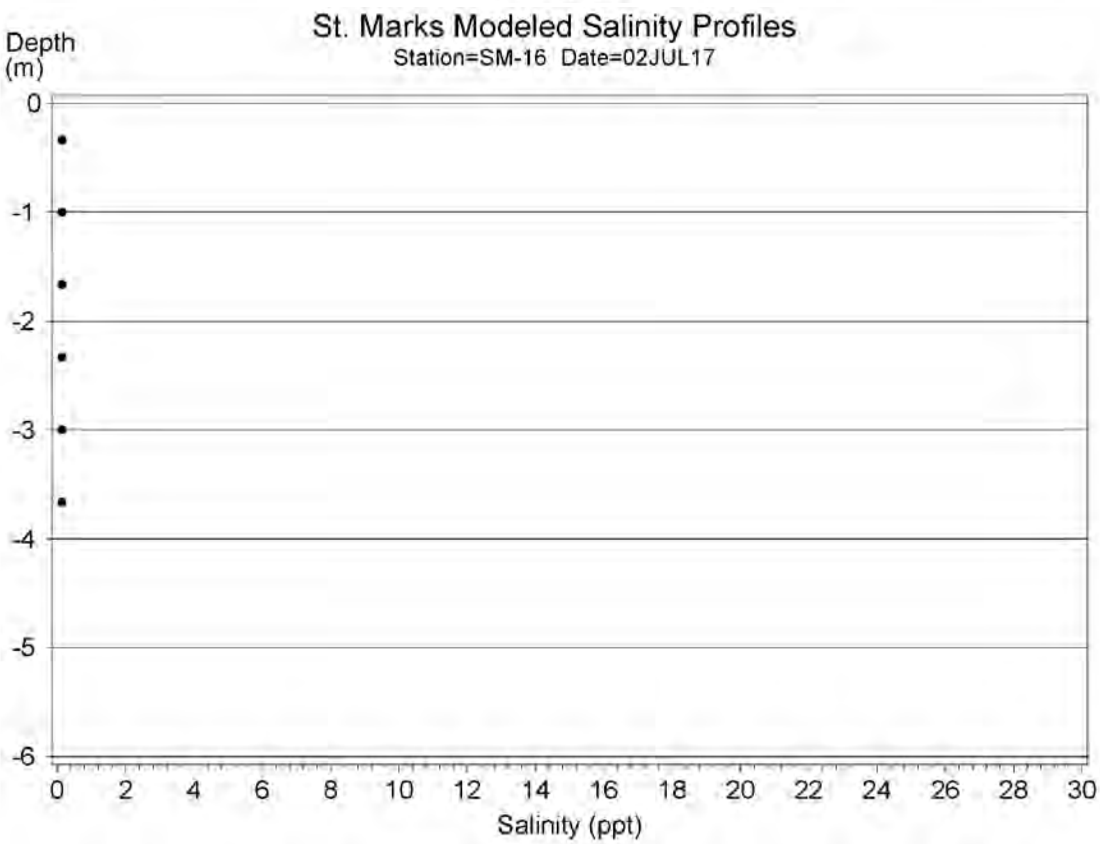
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-16 Date=02JUL17
Depth (m)
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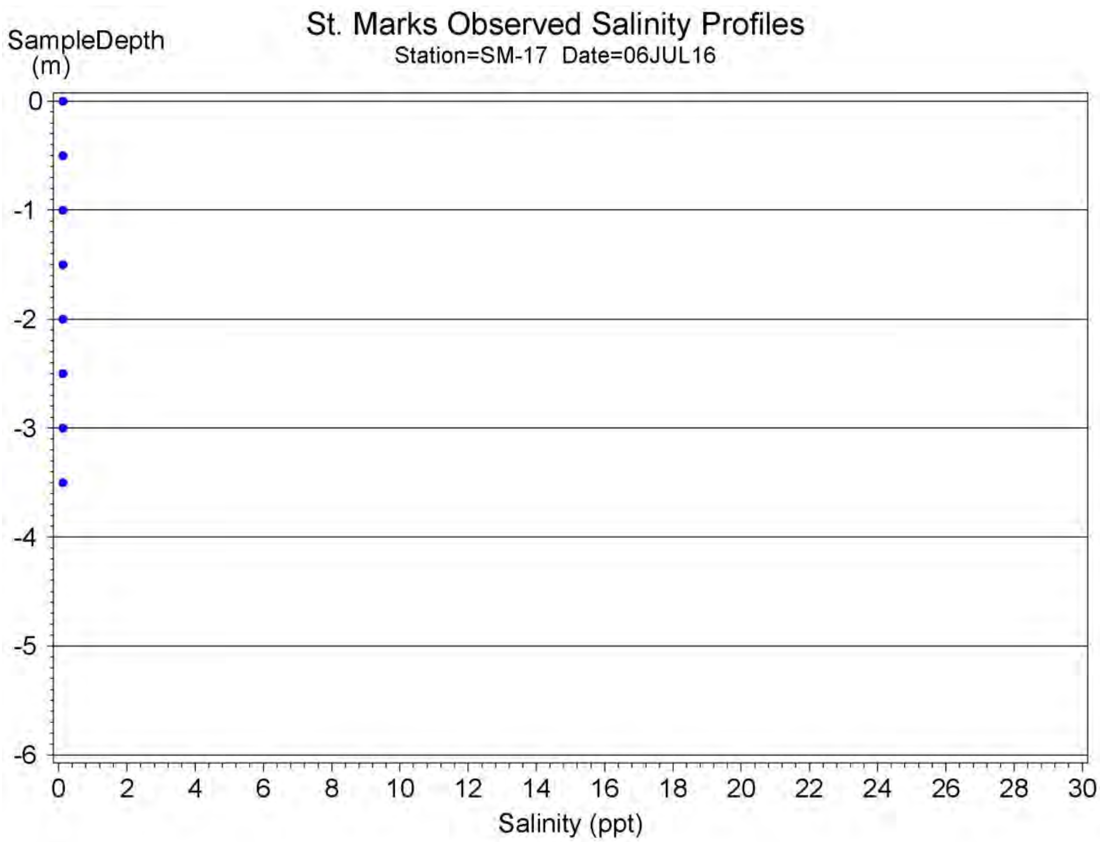
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-17 Date=06JUL16
SampleDepth (m)
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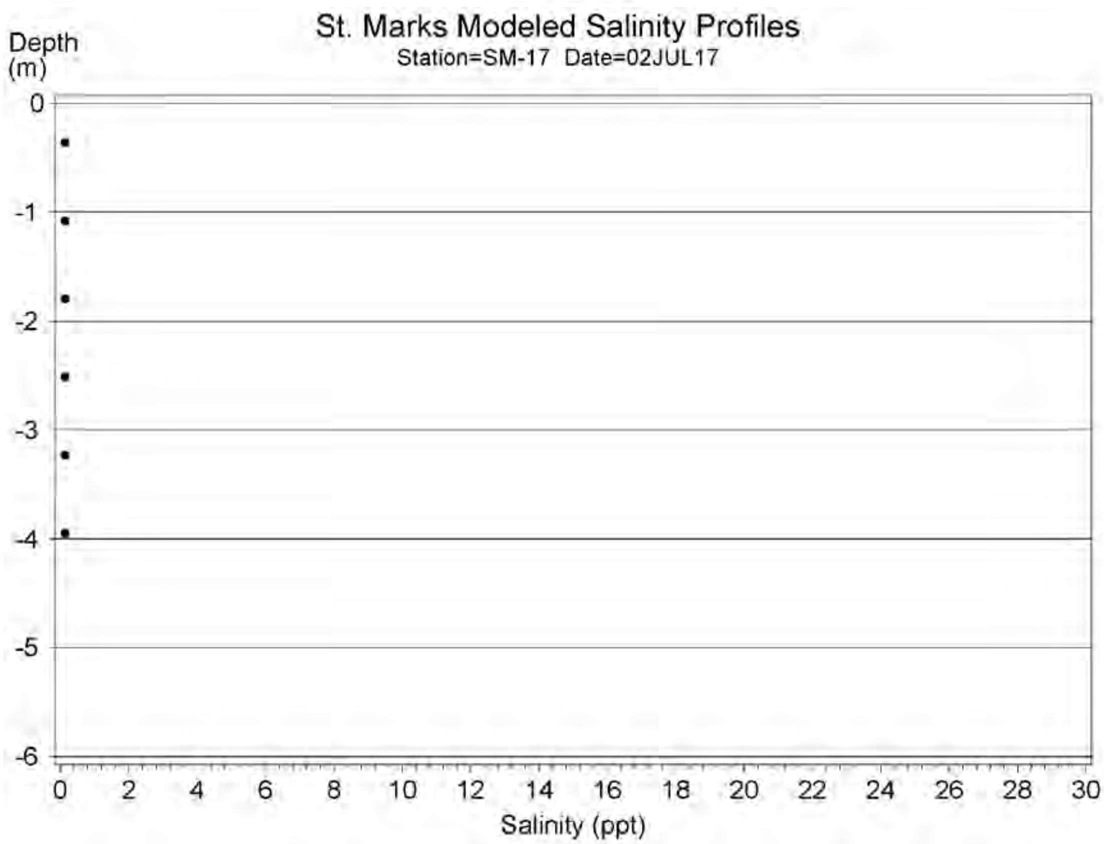
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-17 Date=02JUL17
Depth (m)
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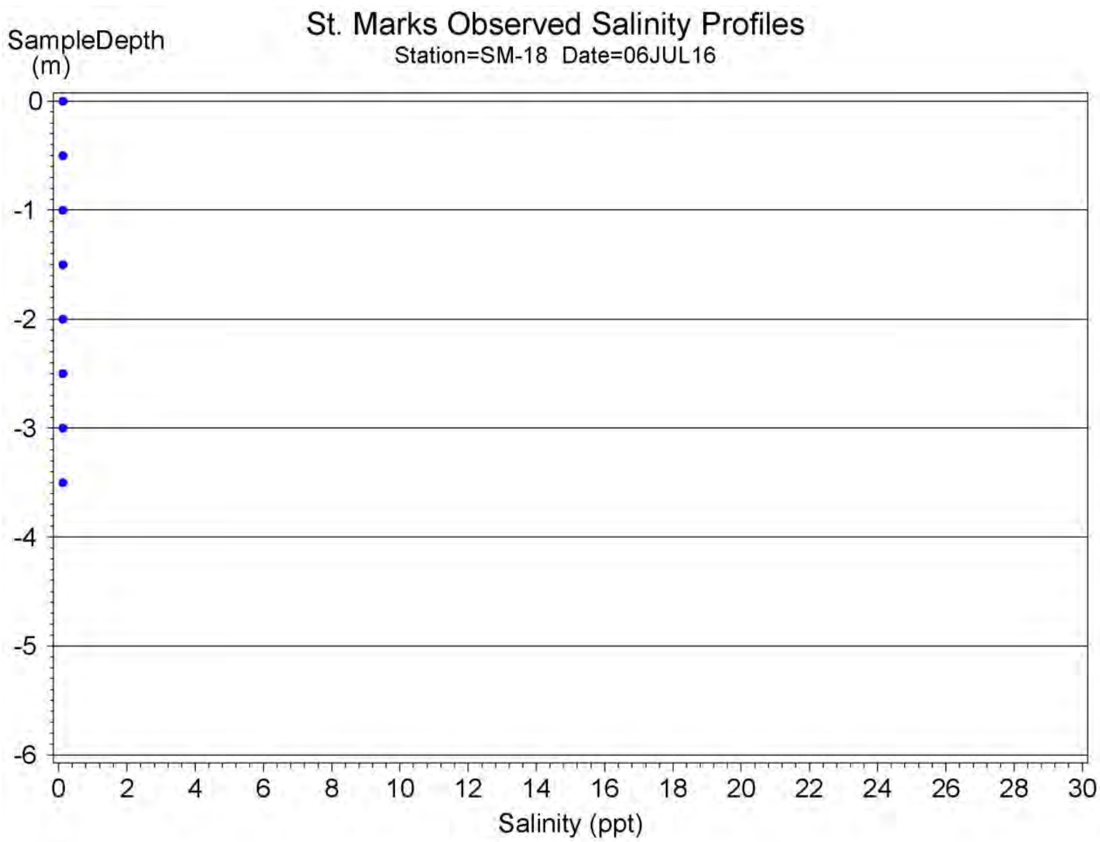
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-18 Date=06JUL16
SampleDepth (m)
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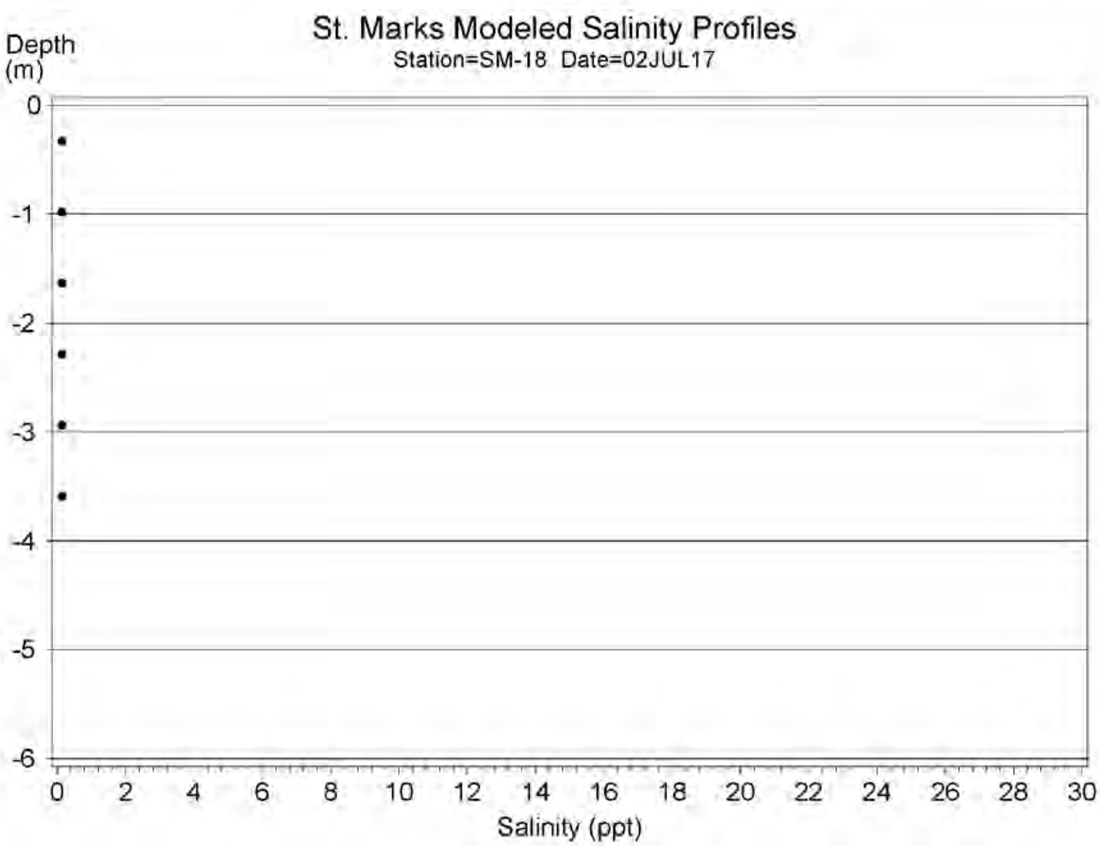
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-18 Date=02JUL17
Depth (m)
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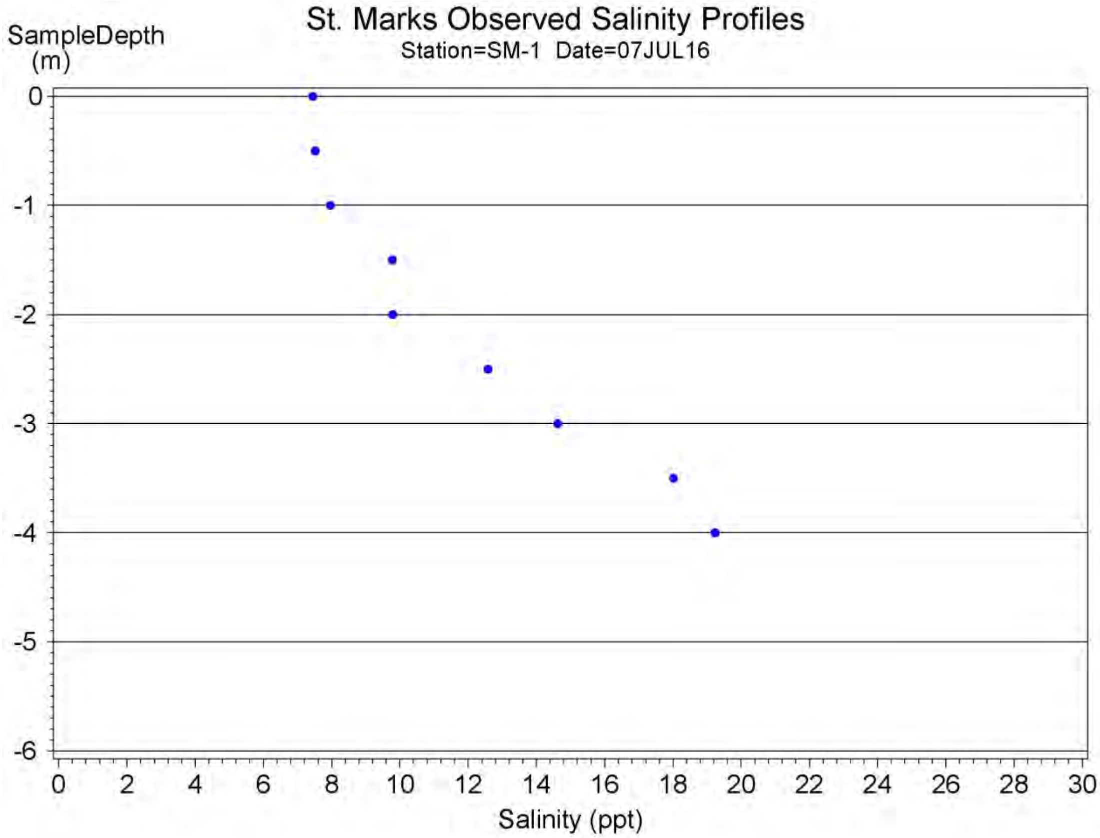
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-1 Date=07JUL16
SampleDepth (m)
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-1
-2
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-5
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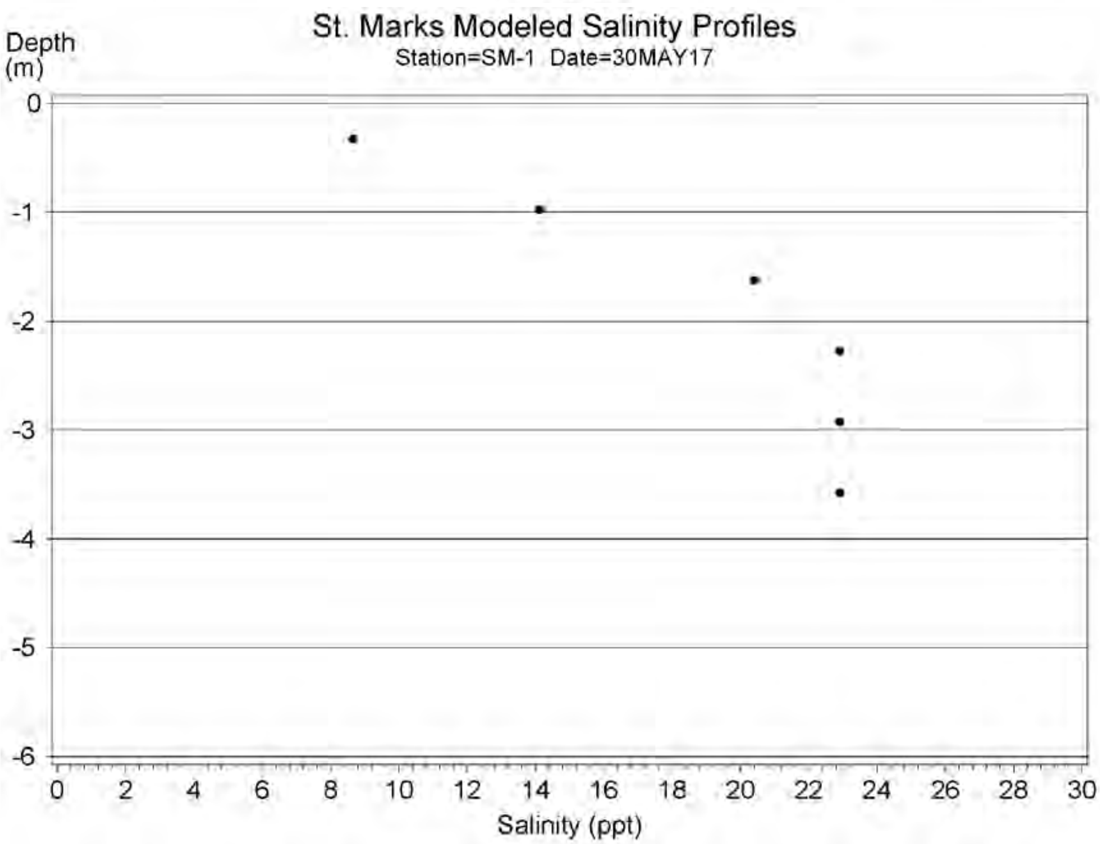
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-1 Date=30MAY17
Depth (m)
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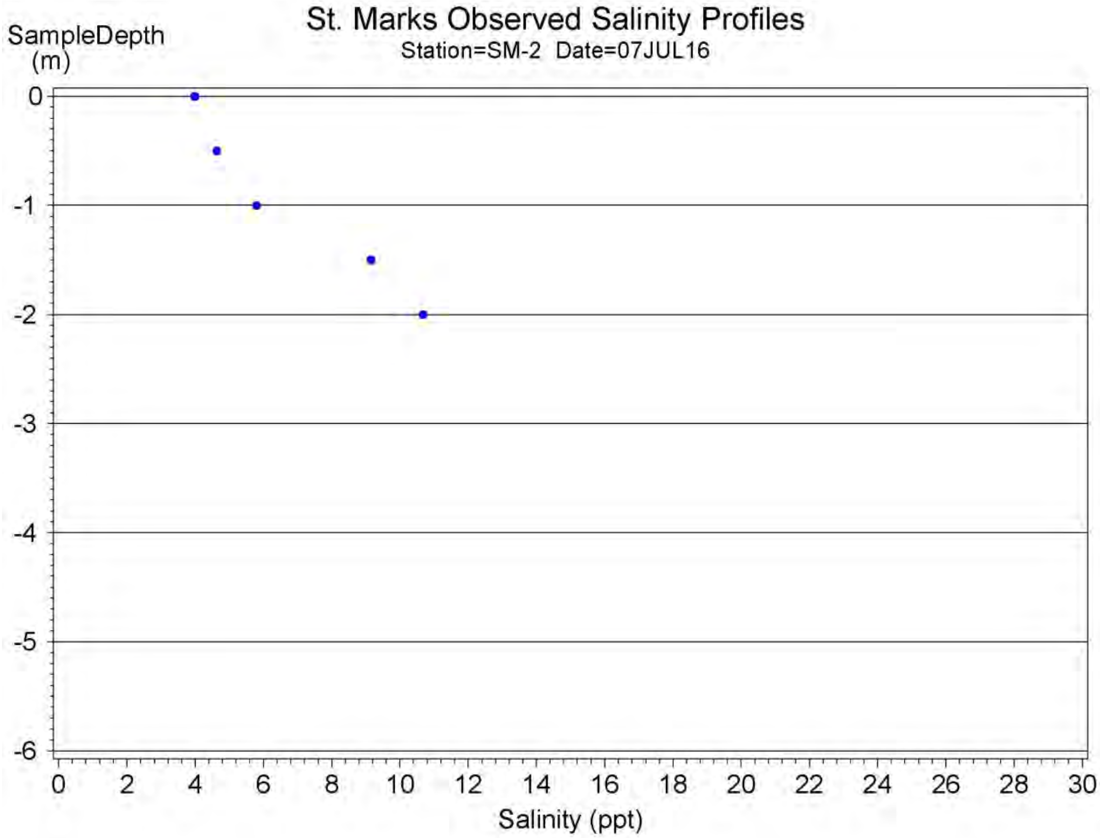
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-2 Date=07JUL16
SampleDepth (m)
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-2
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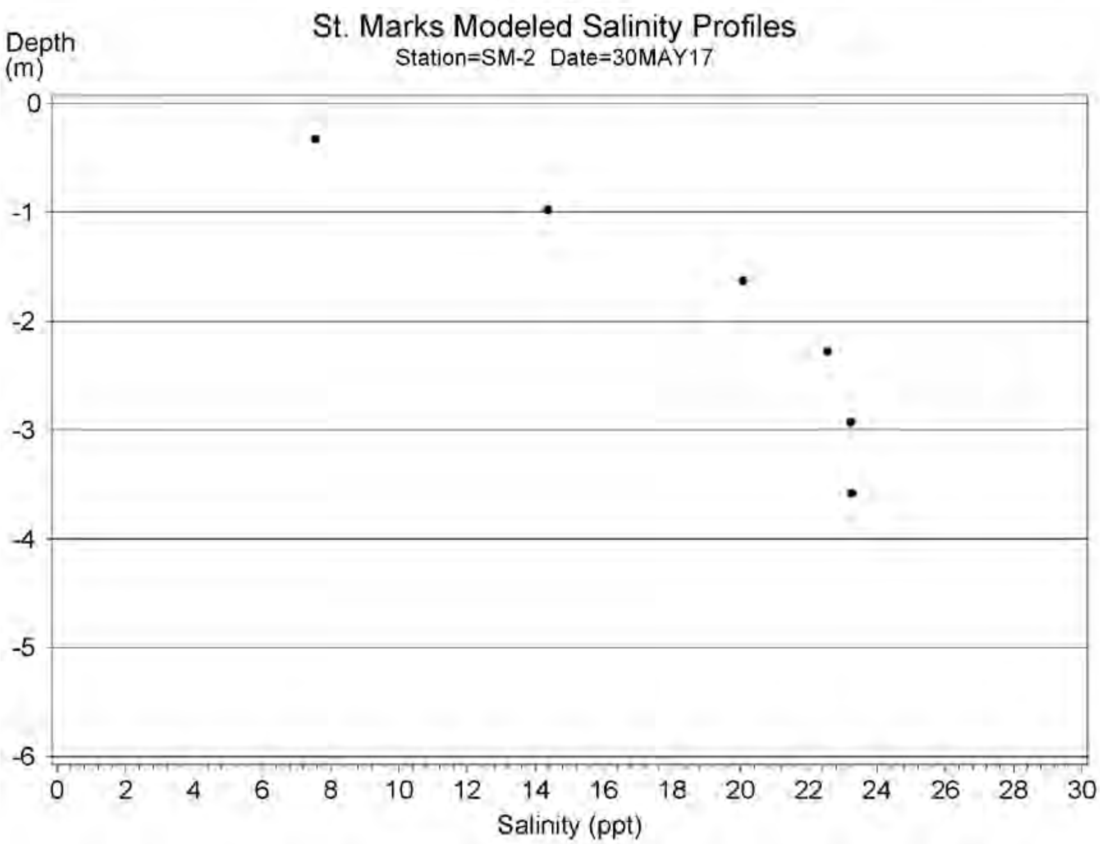
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-2 Date=30MAY17
Depth (m)
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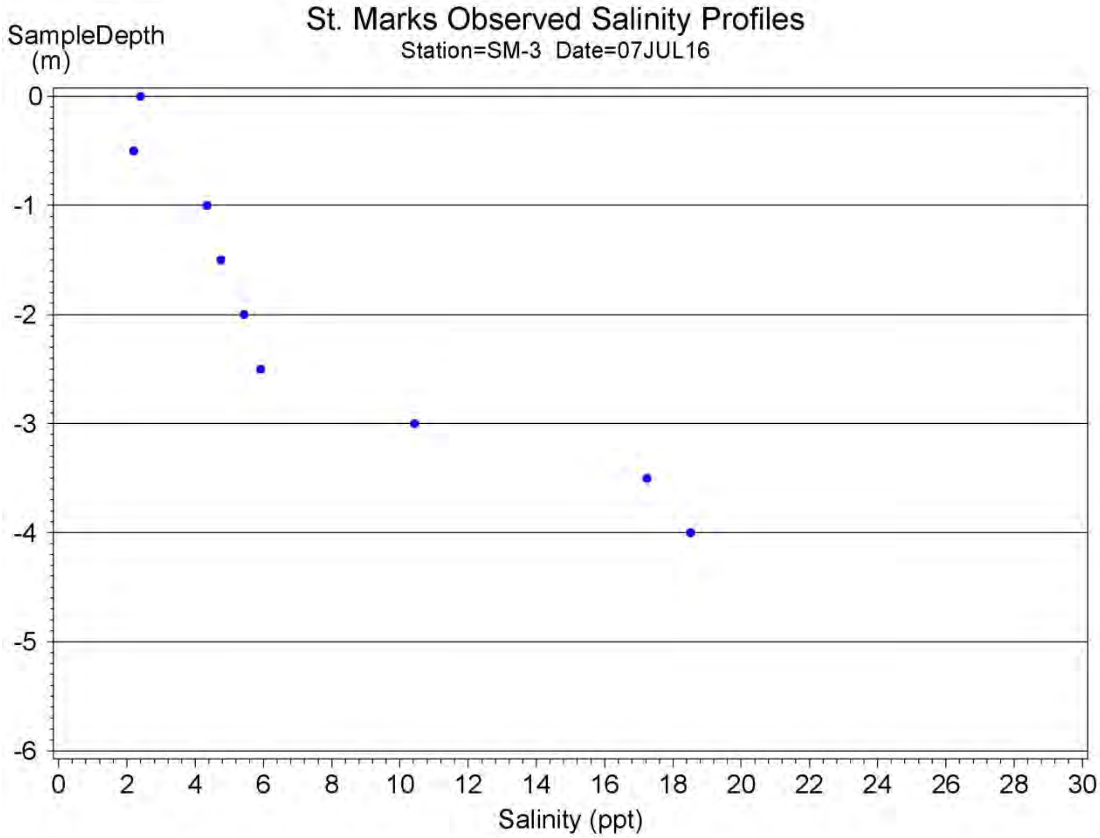
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-3 Date=07JUL16
SampleDepth (m)
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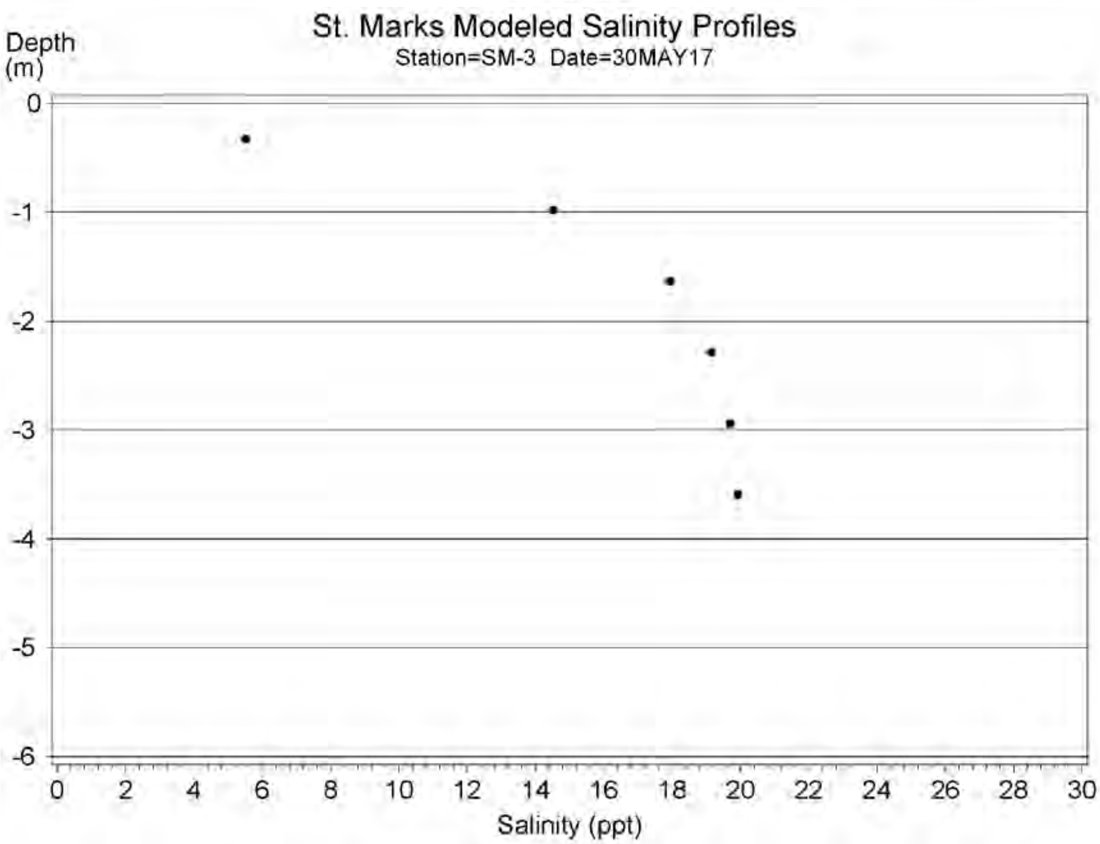
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-3 Date=30MAY17
Depth (m)
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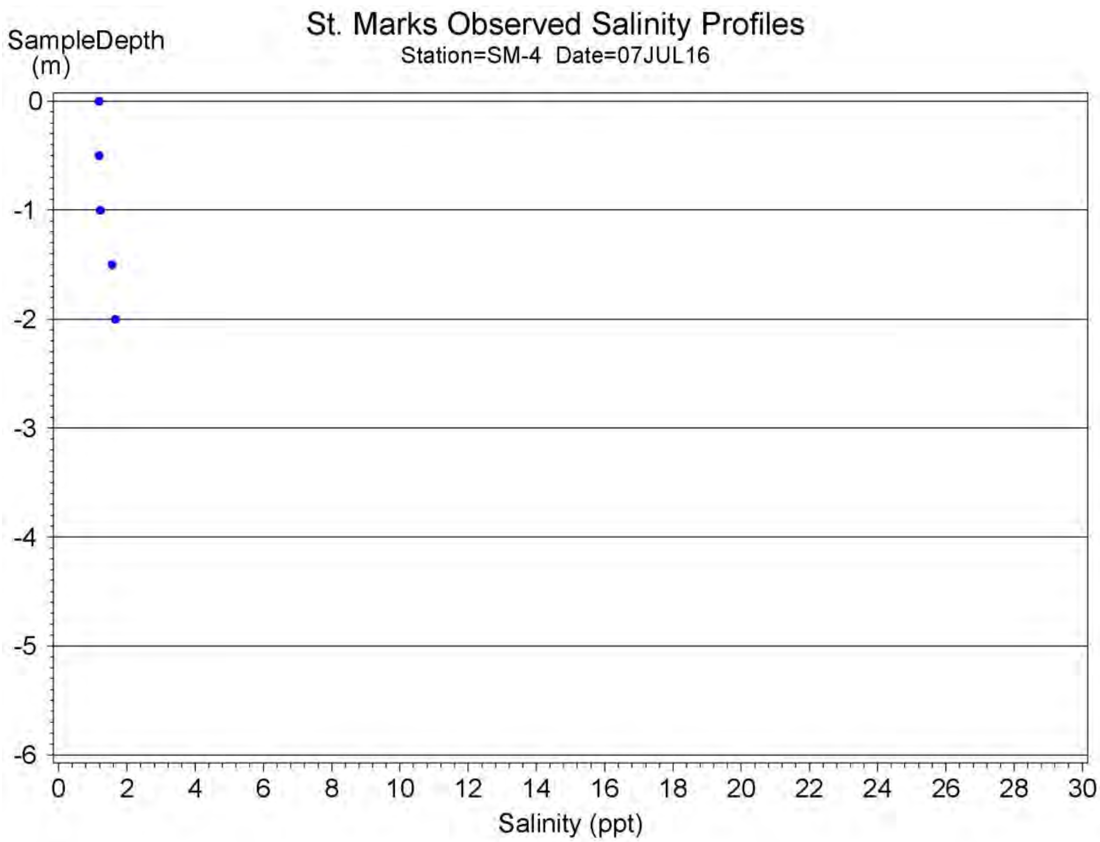
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-4 Date=07JUL16
SampleDepth (m)
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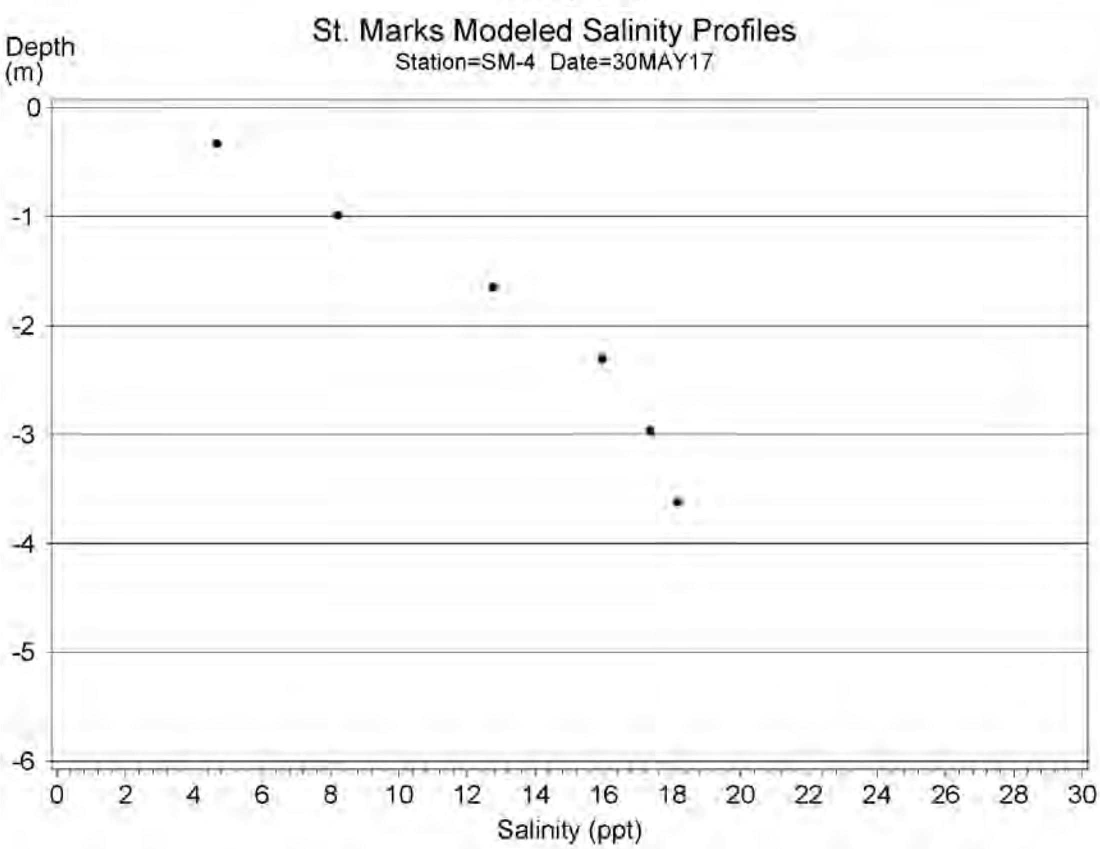
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-4 Date=30MAY17
Depth (m)
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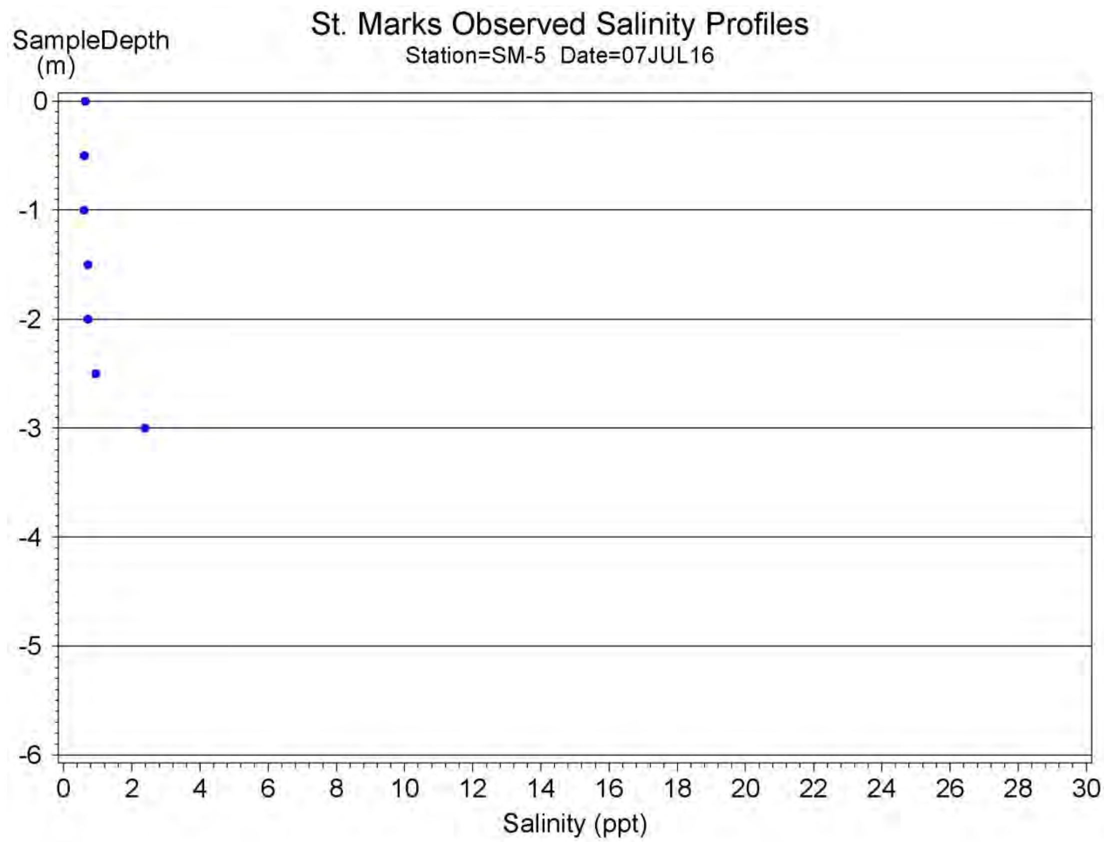
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-5 Date=07JUL16
SampleDepth (m)
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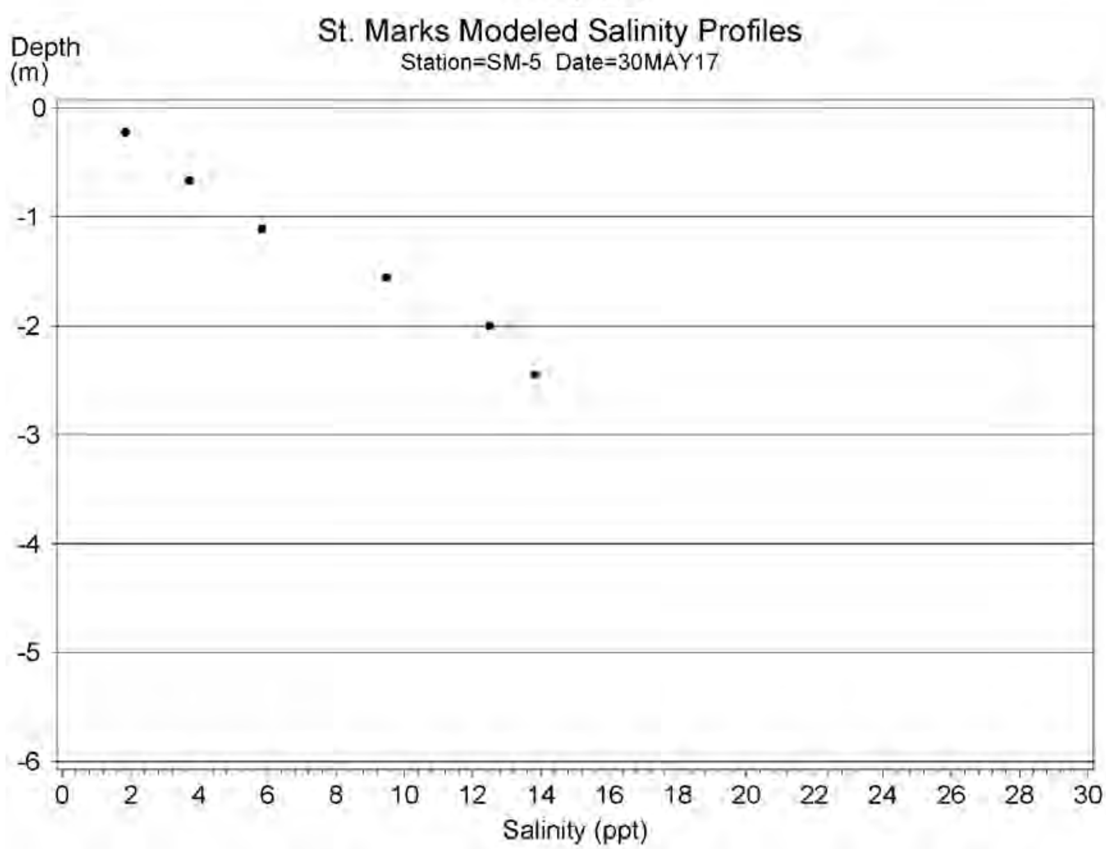
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-5 Date=30MAY17
Depth (m)
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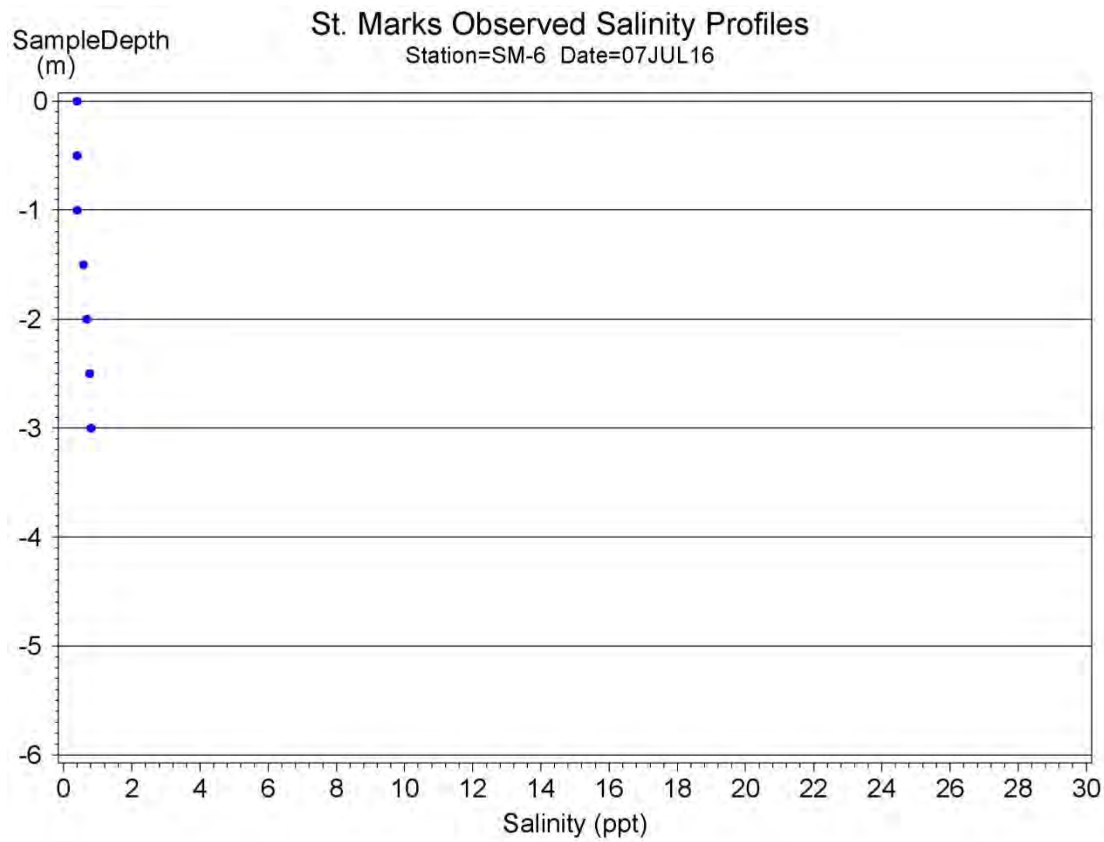
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-6 Date=07JUL16
SampleDepth
(m)
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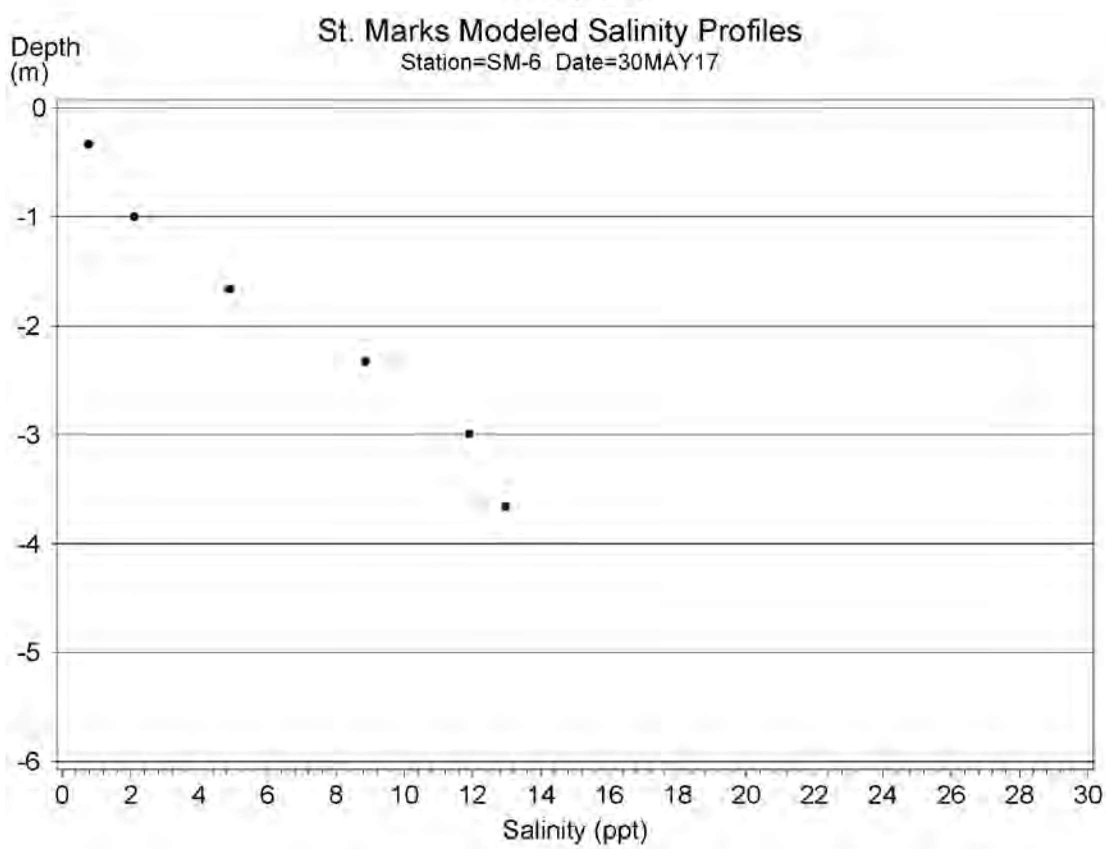
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-6 Date=30MAY17
Depth
(m)
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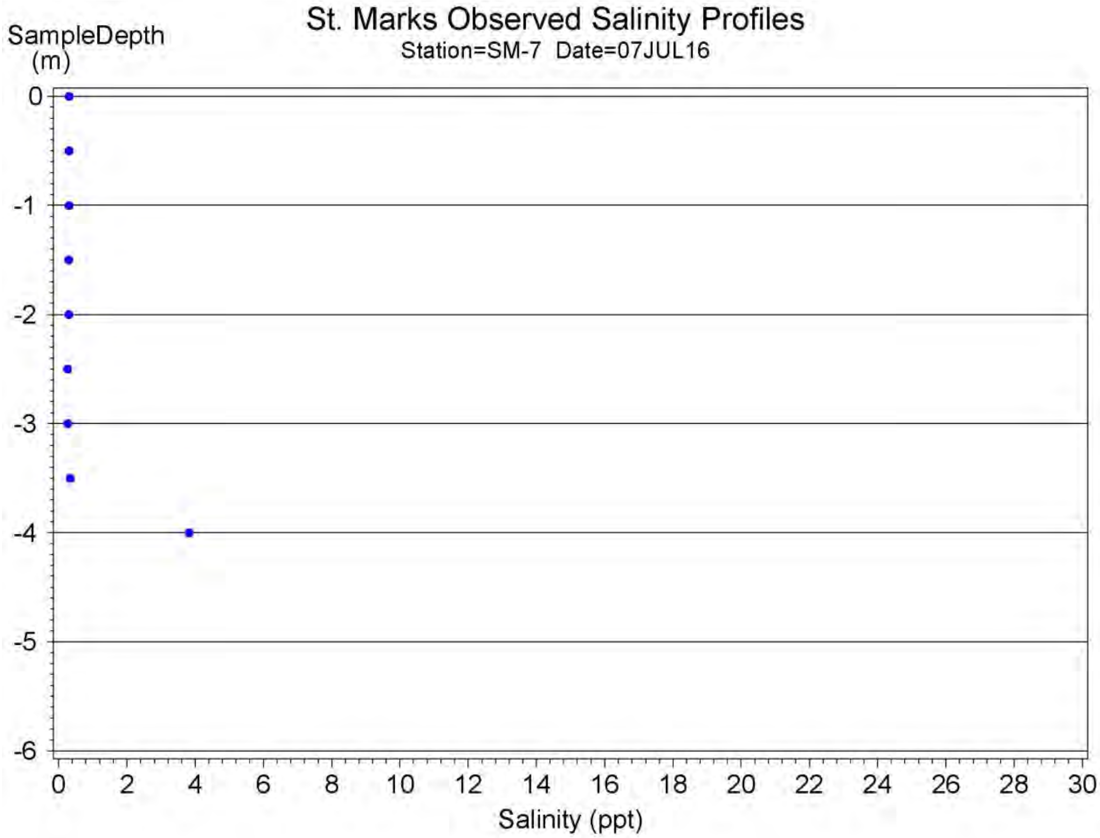
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-7 Date=07JUL16
SampleDepth (m)
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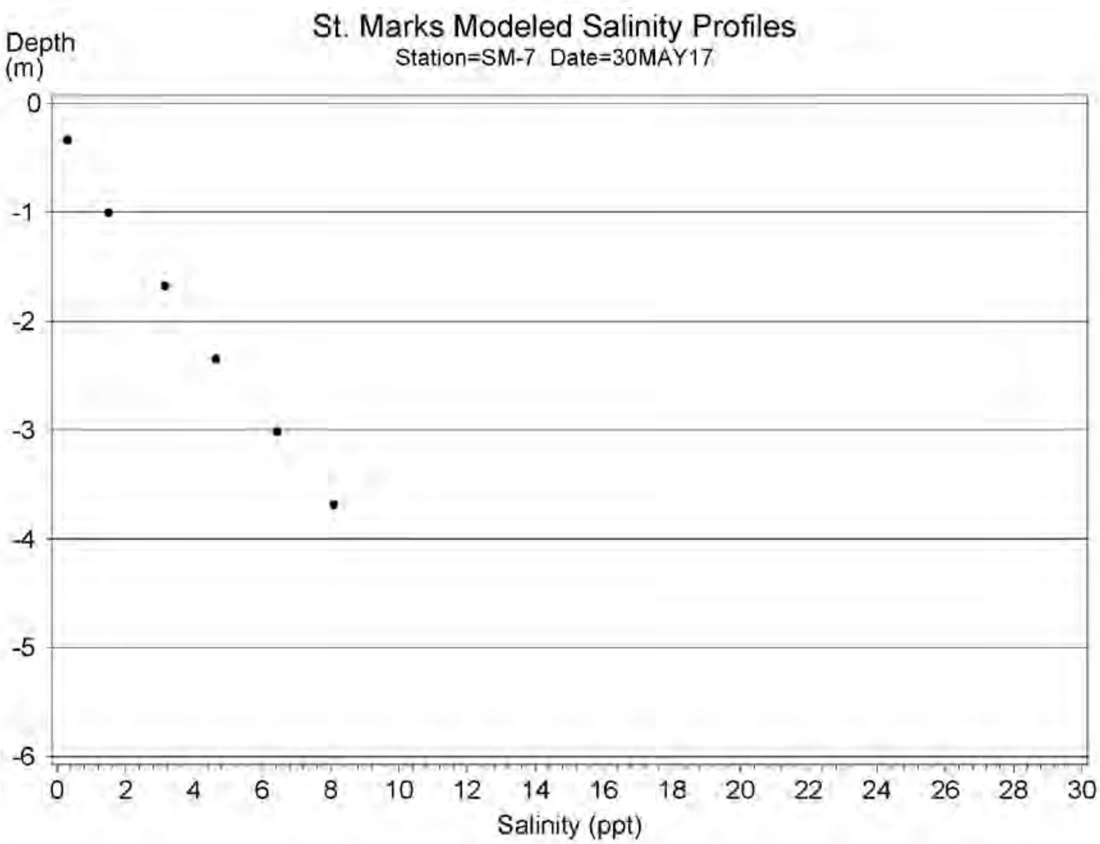
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-7 Date=30MAY17
Depth (m)
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-5
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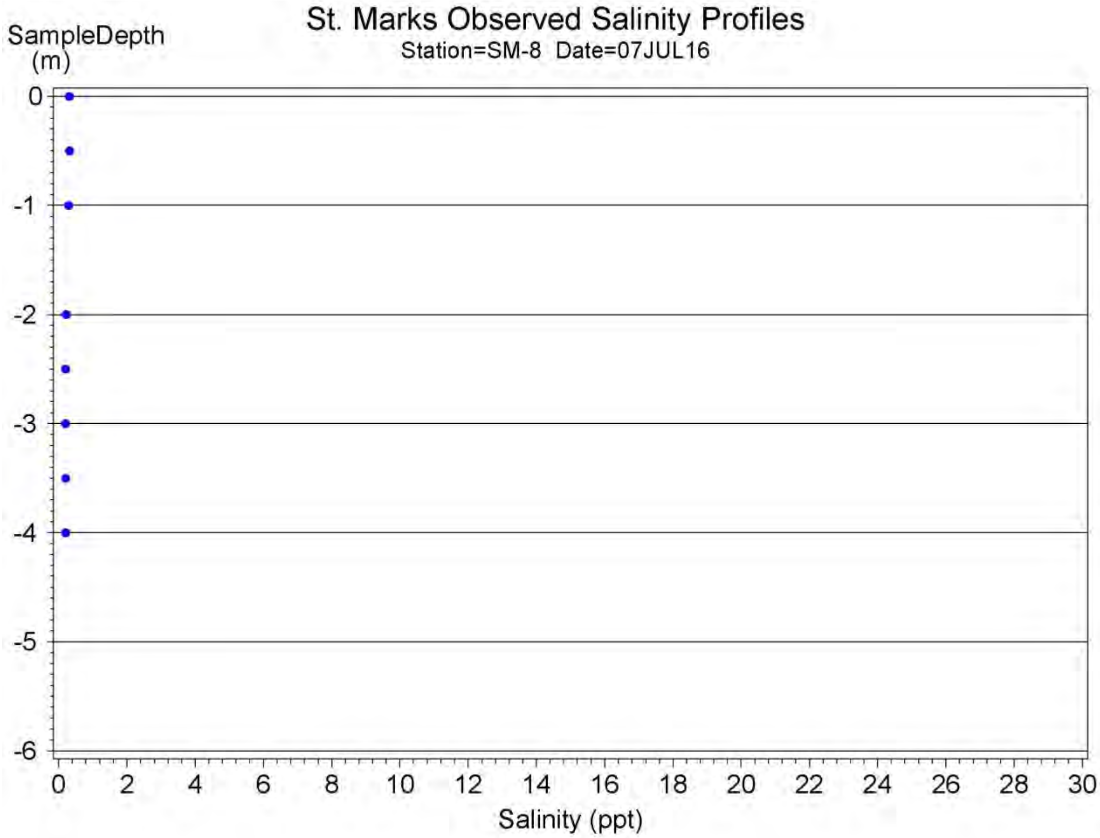
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-8 Date=07JUL16
SampleDepth
(m)
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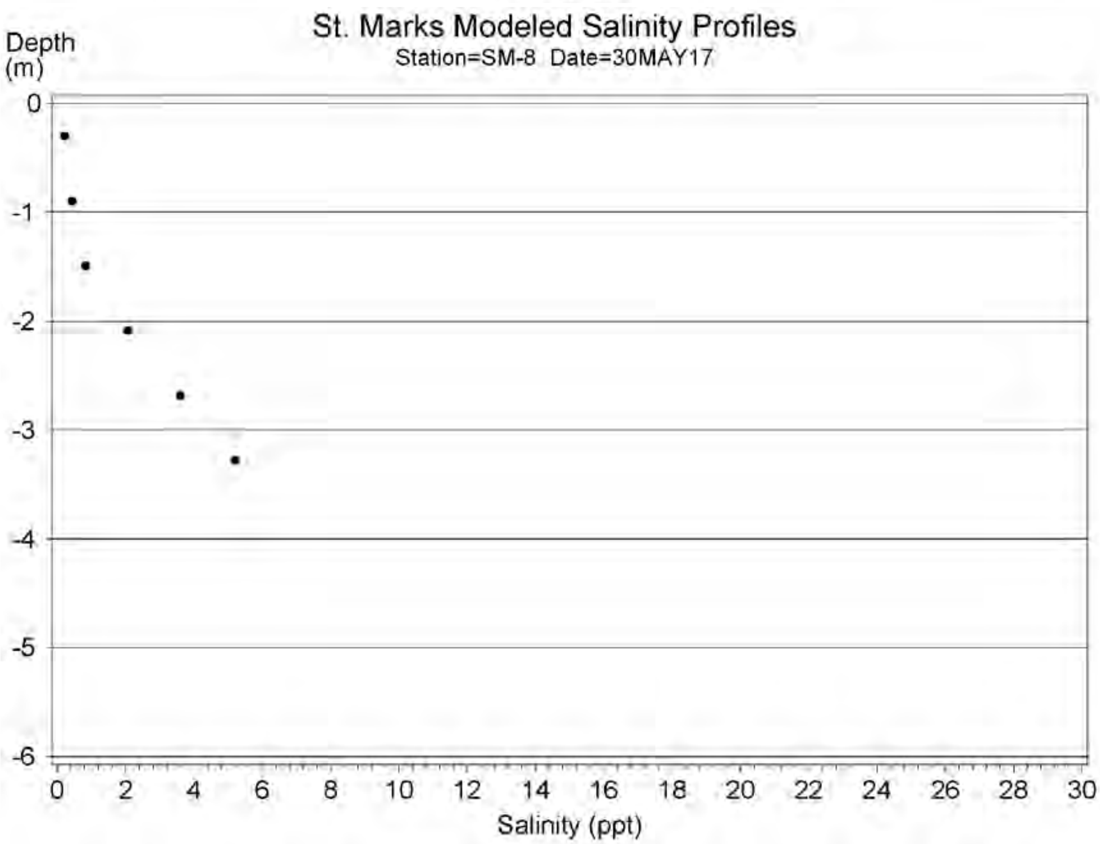
-2
-3
-4
-5
-6
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-8 Date=30MAY17
Depth
(m)
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-1
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-5
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8
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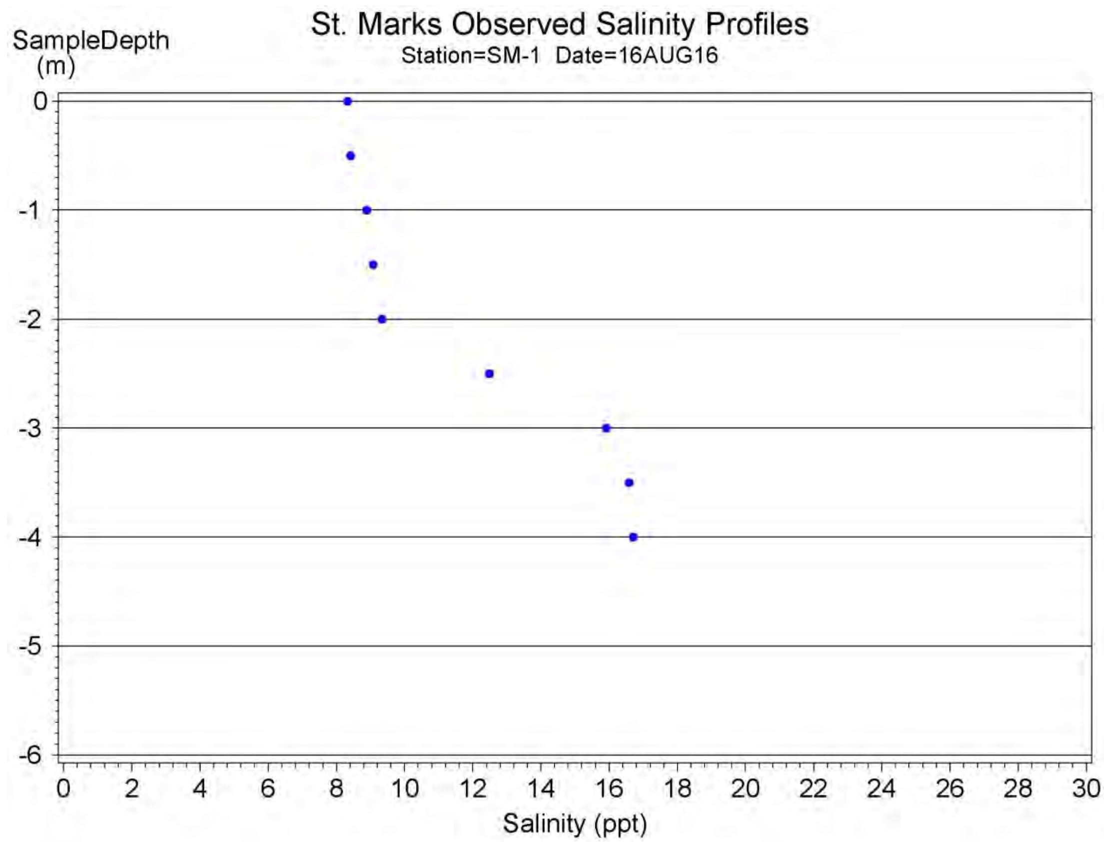
12
14
16
18
20
22
24
26
28
30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-1 Date=16AUG16
SampleDepth (m)
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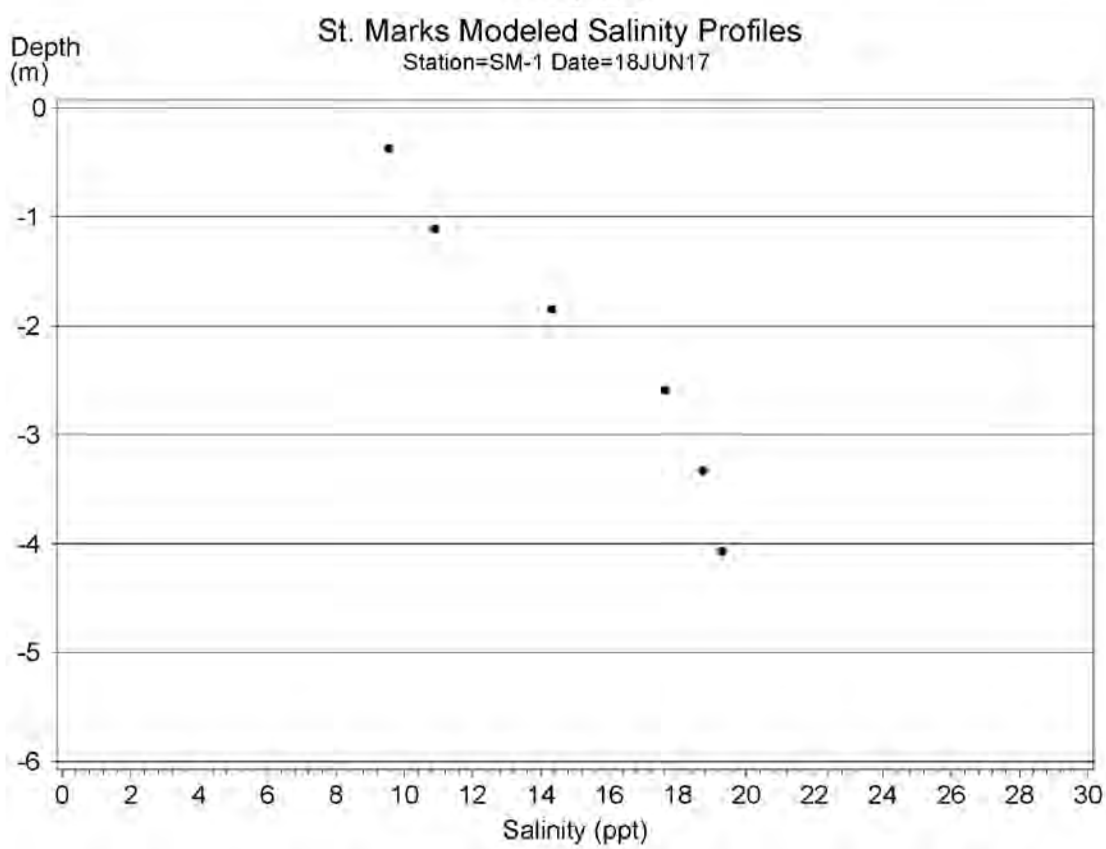
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-1 Date=18JUN17
Depth (m)
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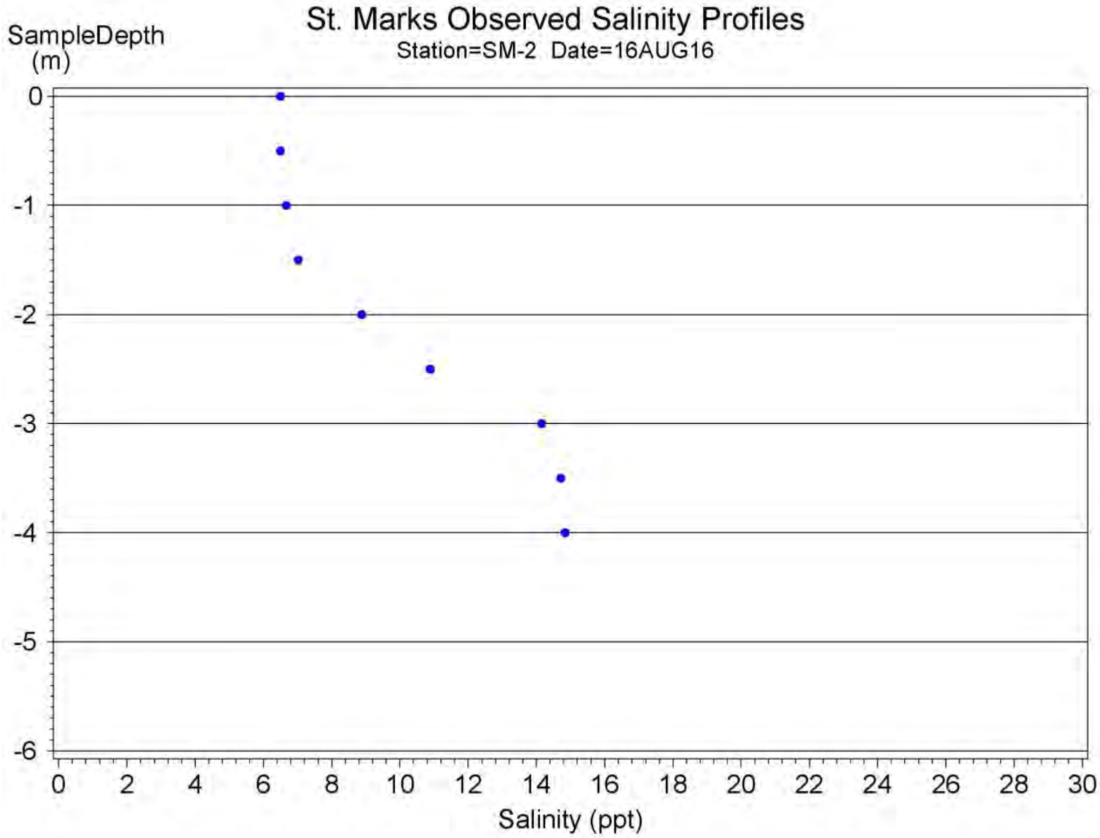
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-2 Date=16AUG16
SampleDepth (m)
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-5
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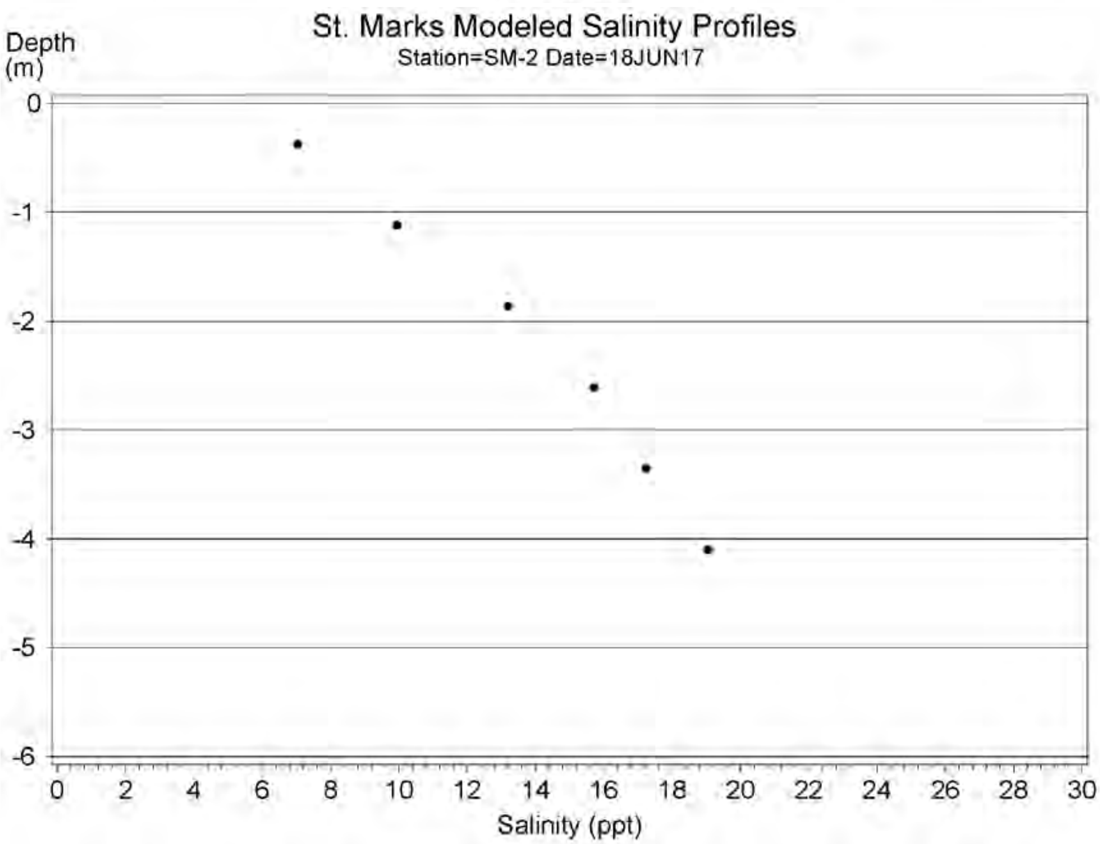
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-2 Date=18JUN17
Depth (m)
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-5
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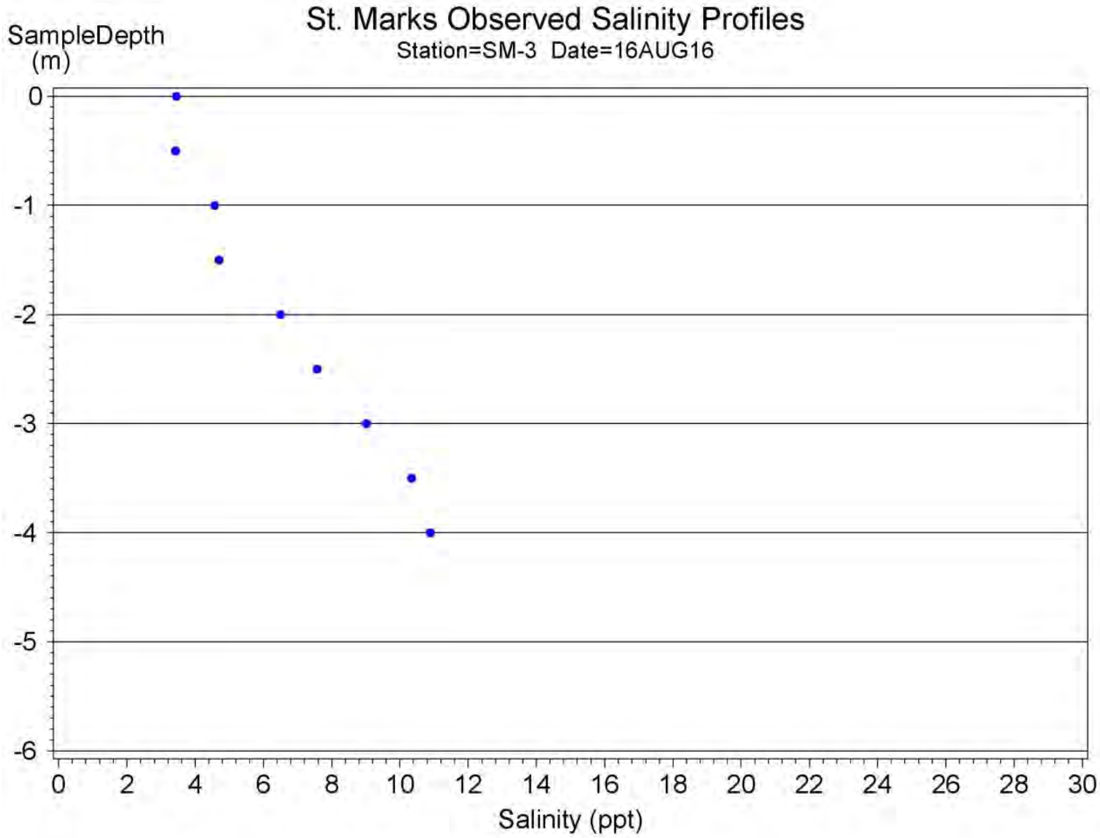
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-3 Date=16AUG16
SampleDepth (m)
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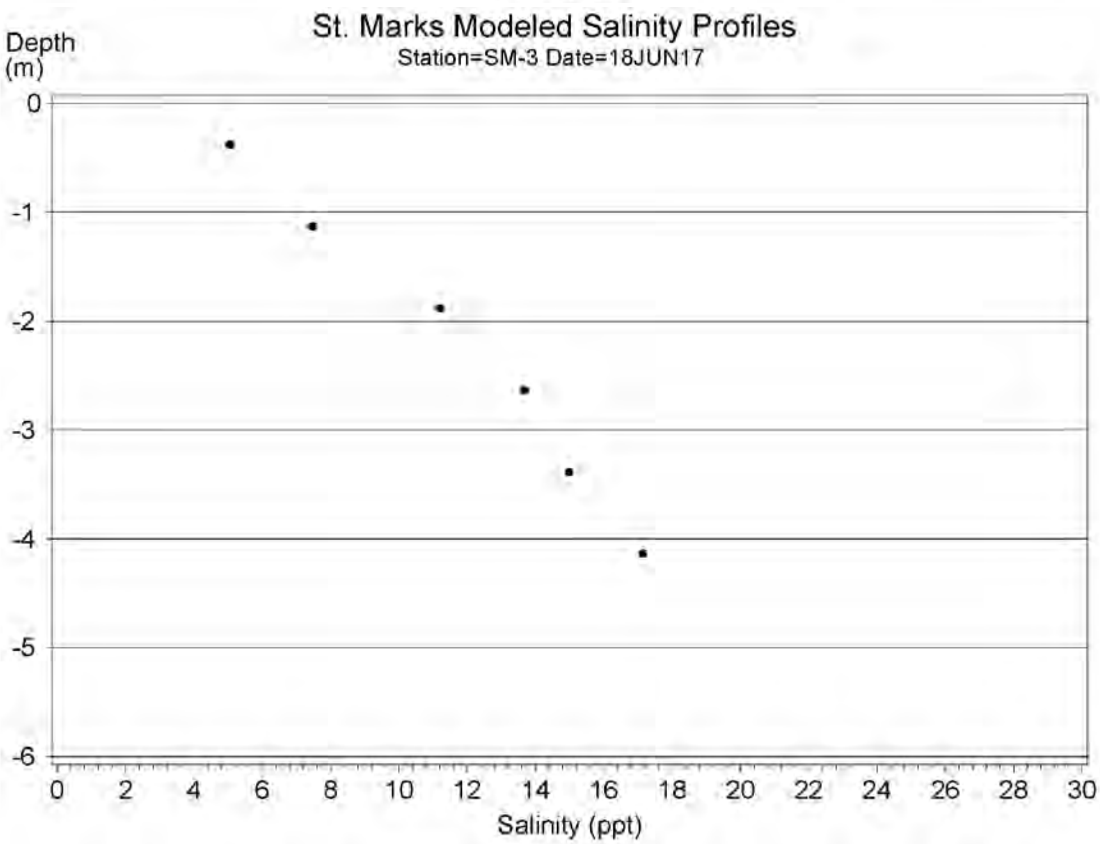
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-3 Date=18JUN17
Depth (m)
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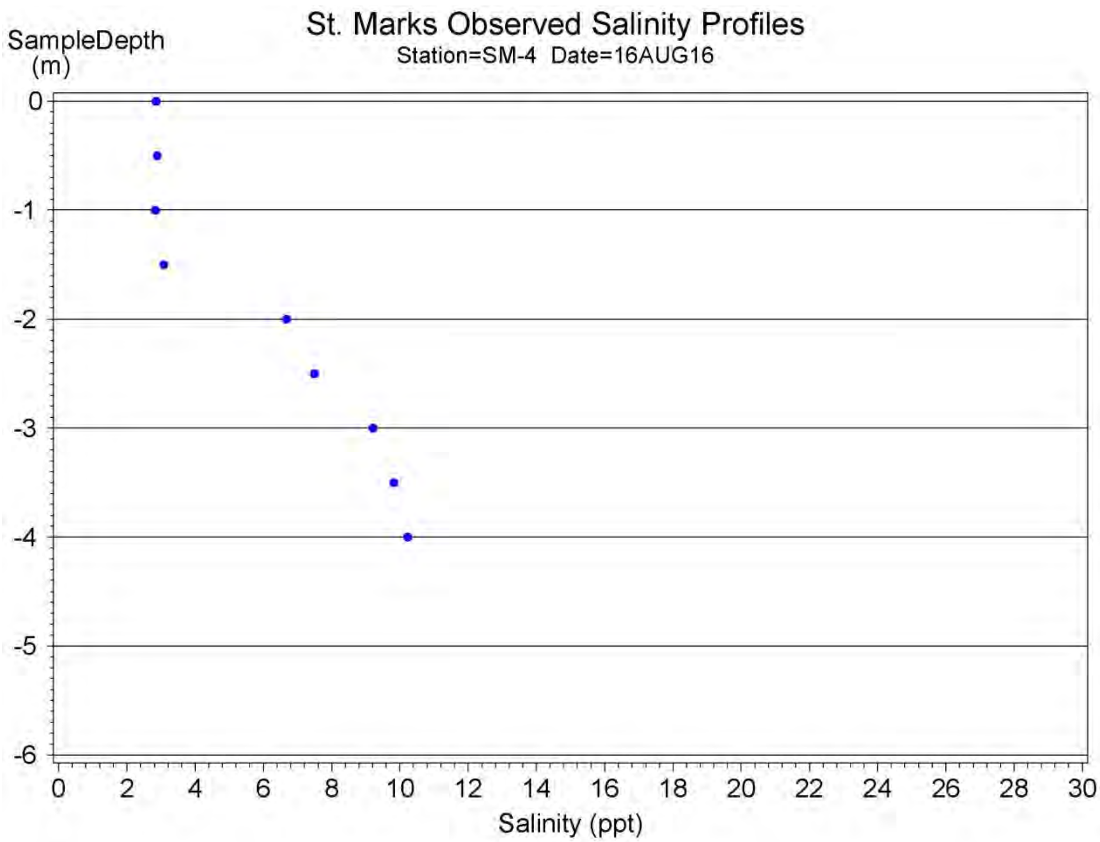
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-4 Date=16AUG16
SampleDepth (m)
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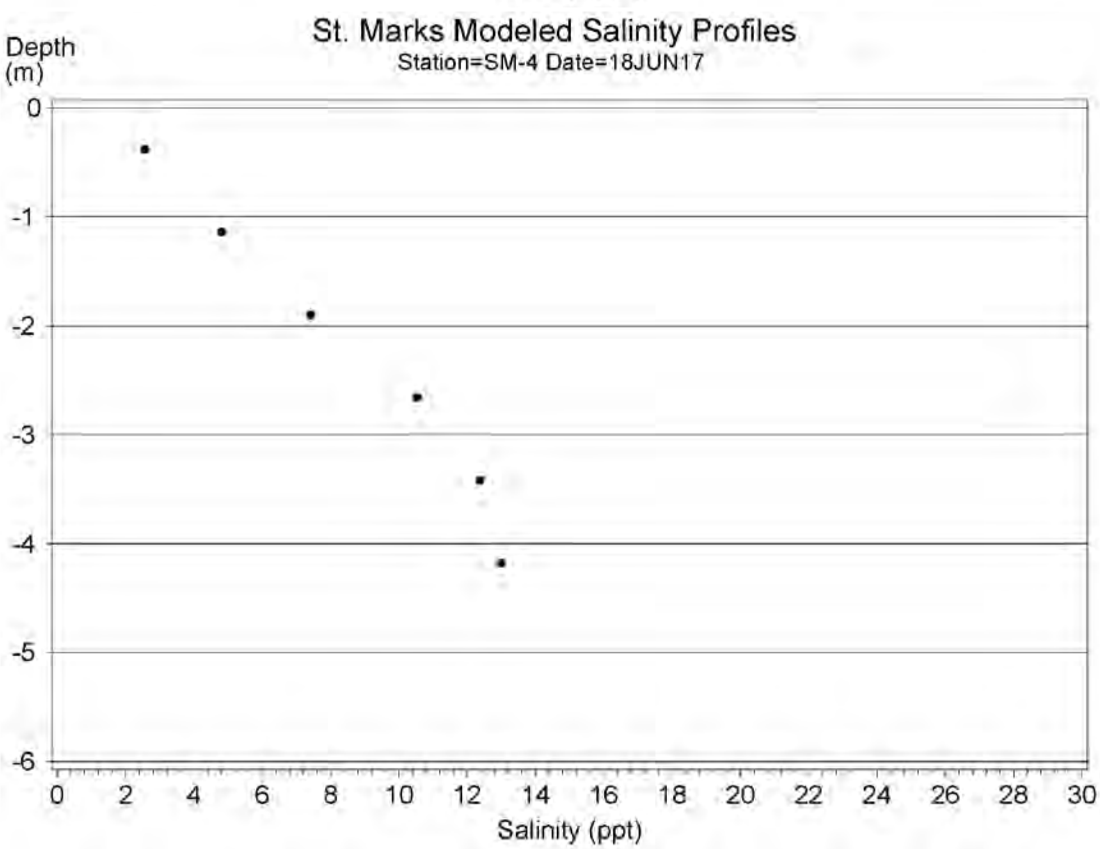
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-4 Date=18JUN17
Depth (m)
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-1
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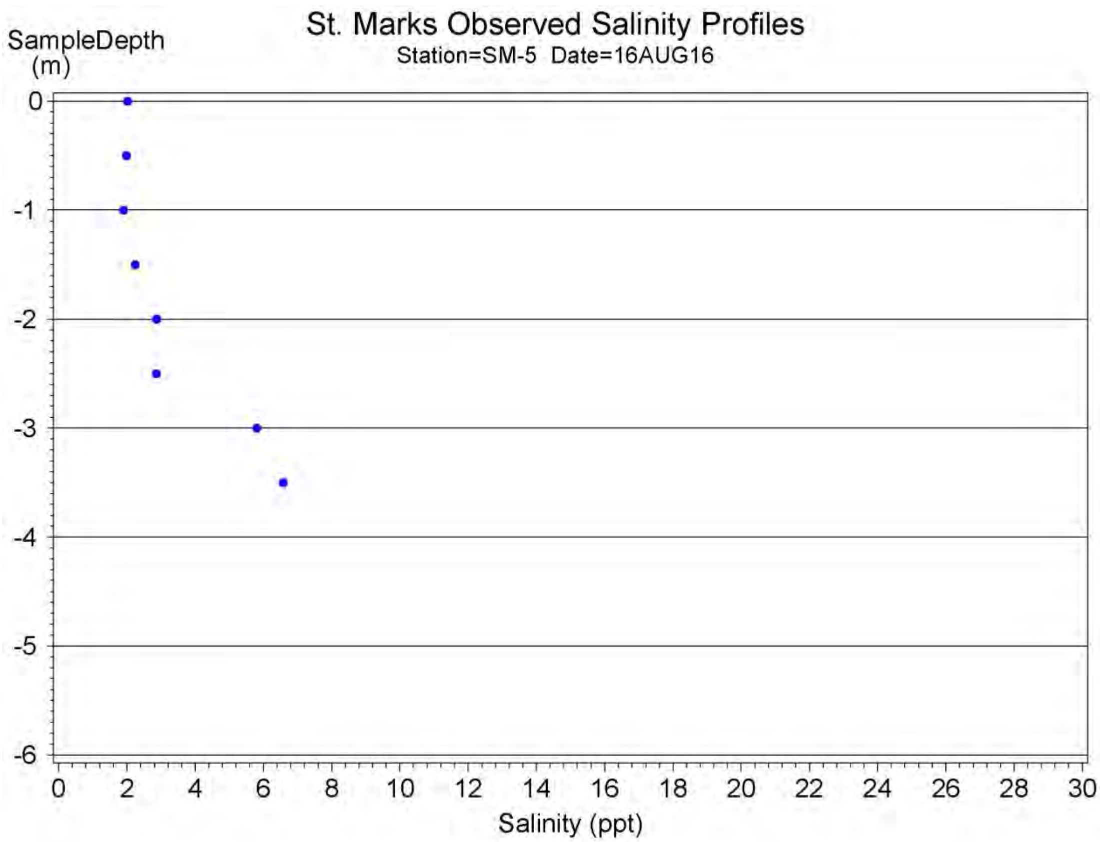
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-5 Date=16AUG16
SampleDepth (m)
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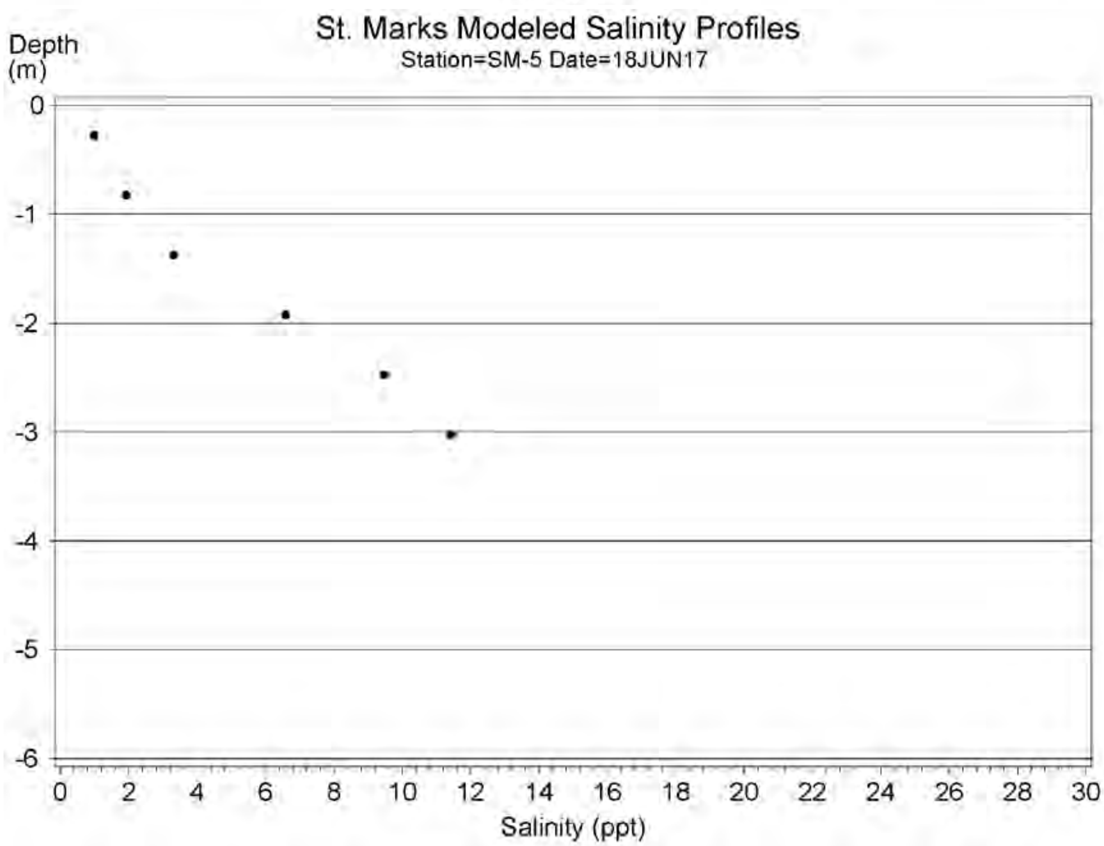
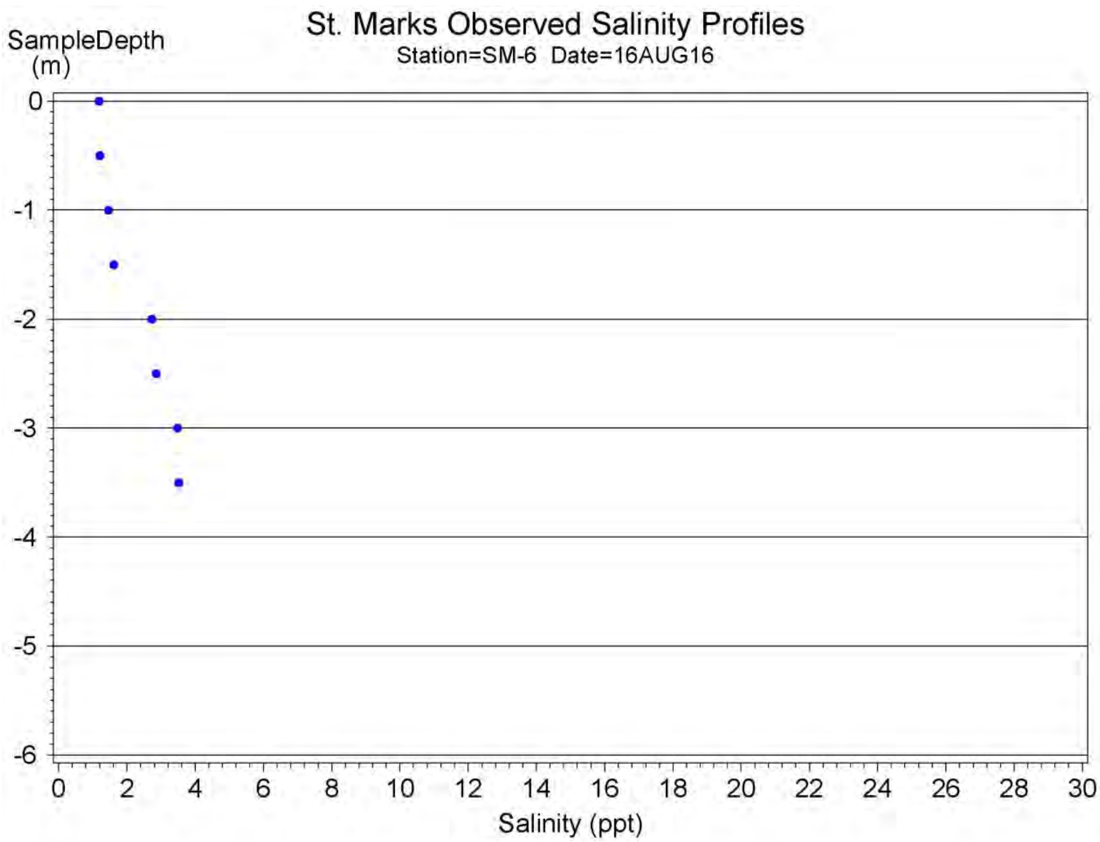
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-5 Date=18JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-6 Date=16AUG16
SampleDepth (m)
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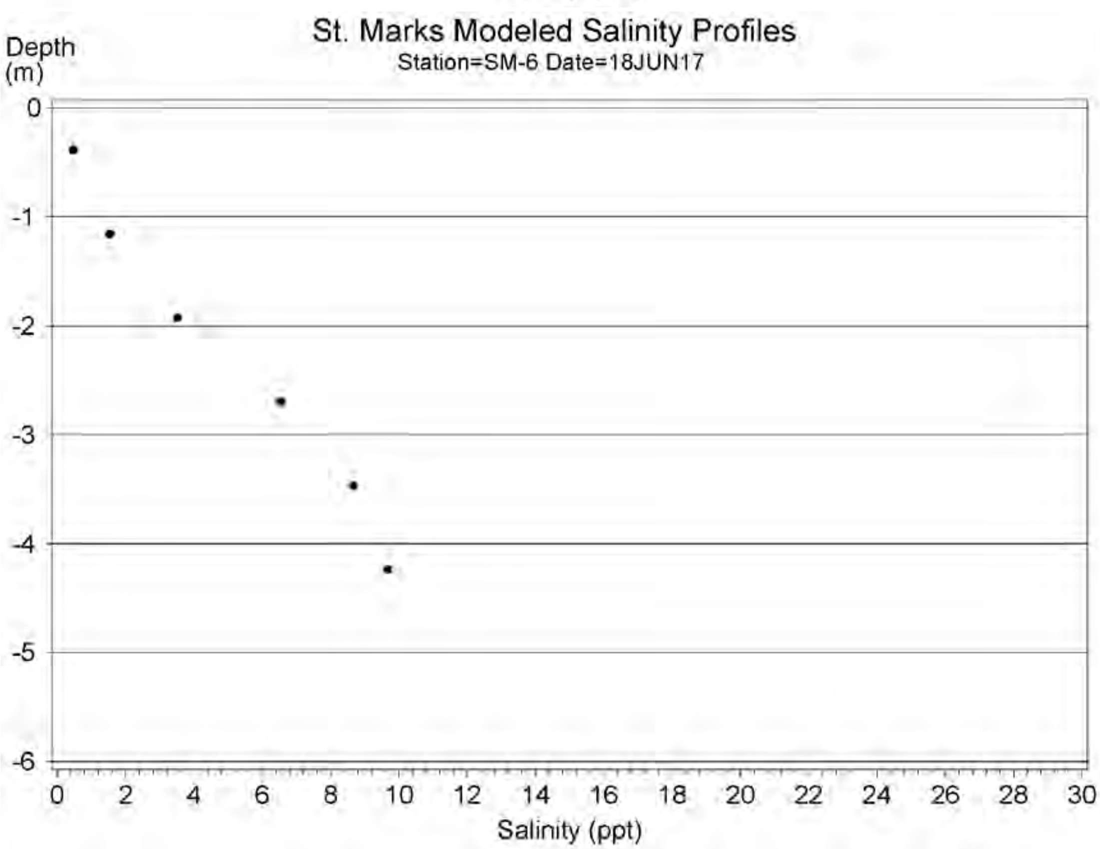
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-6 Date=18JUN17
Depth (m)
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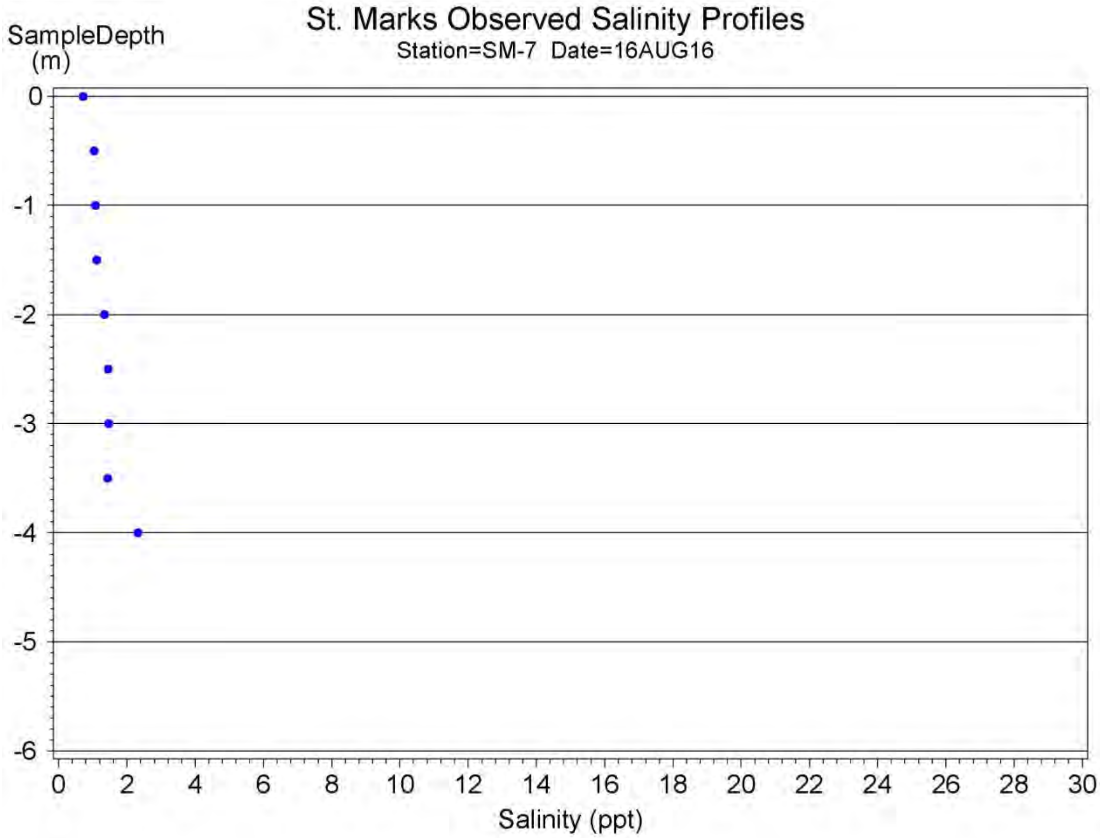
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-7 Date=16AUG16
SampleDepth (m)
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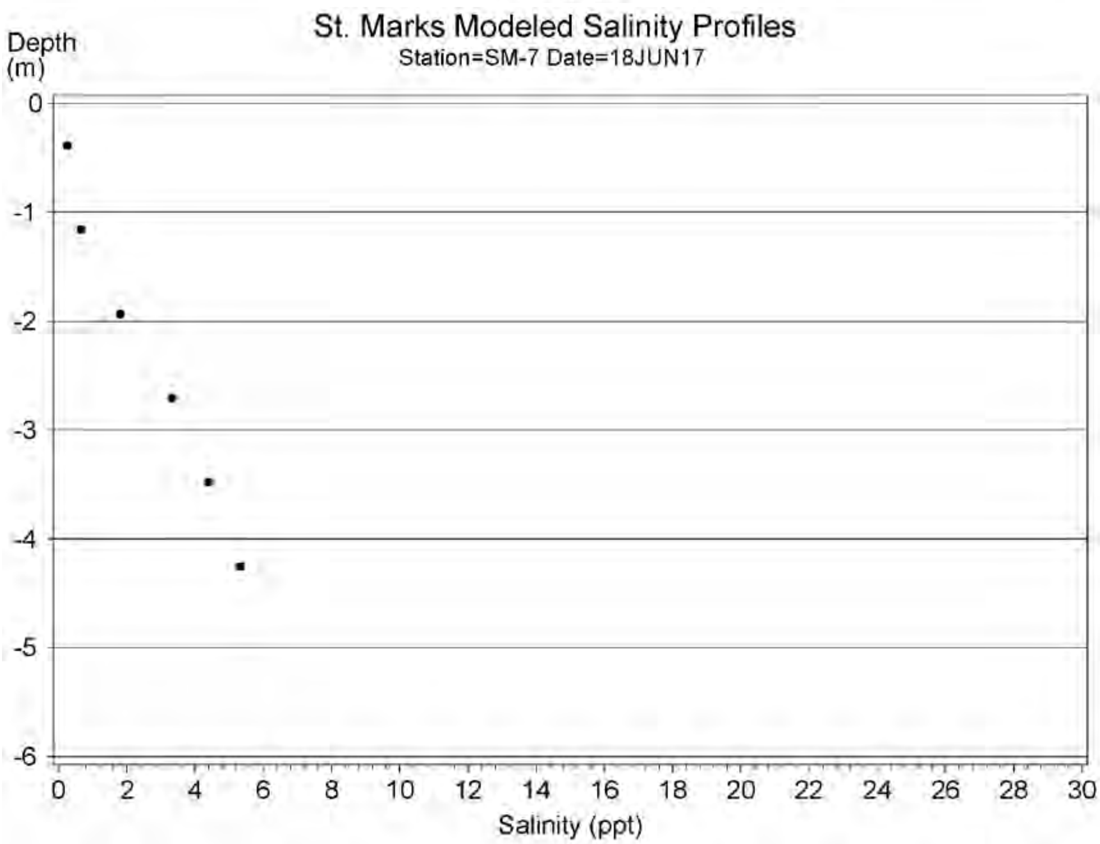
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-7 Date=18JUN17
Depth (m)
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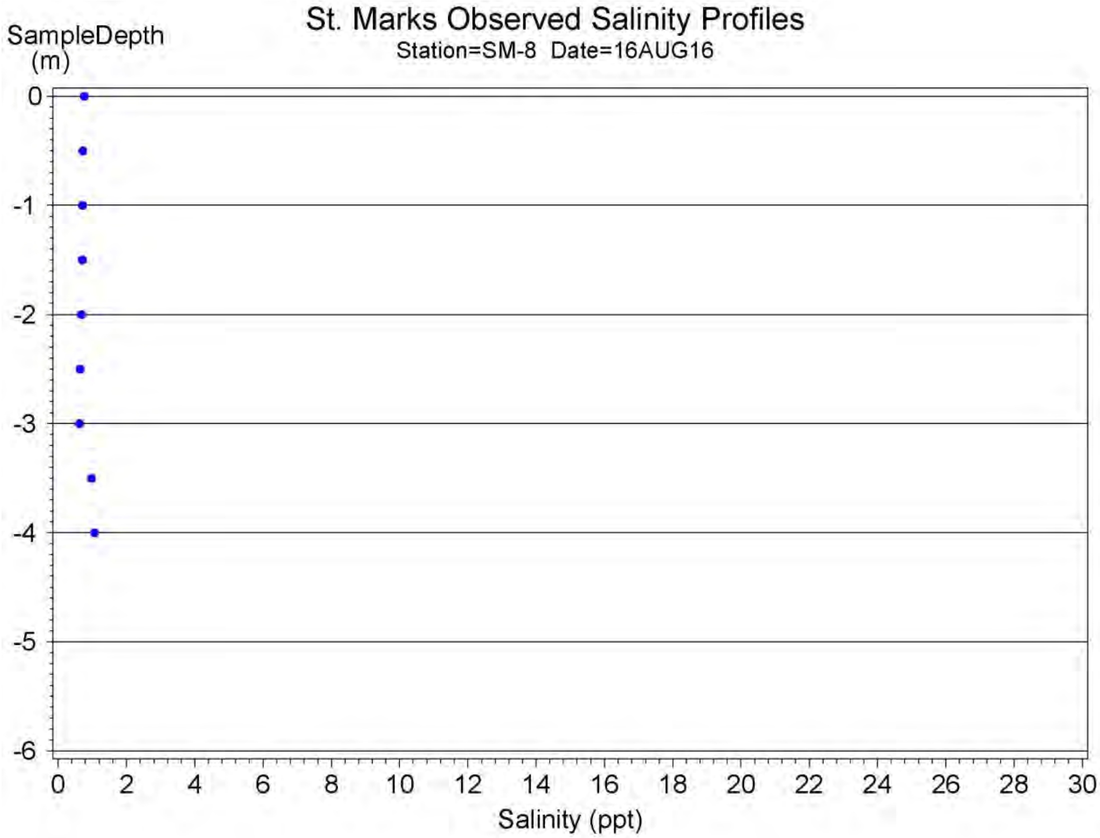
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-8 Date=16AUG16
SampleDepth (m)
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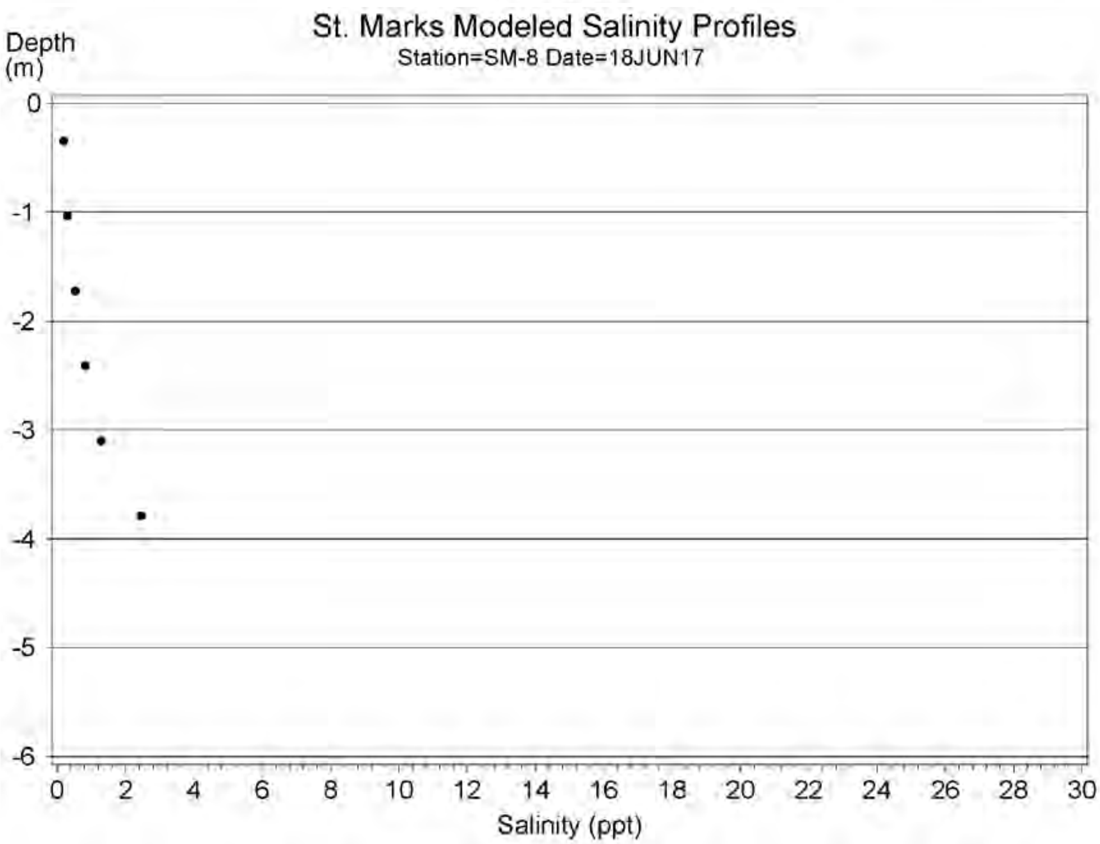
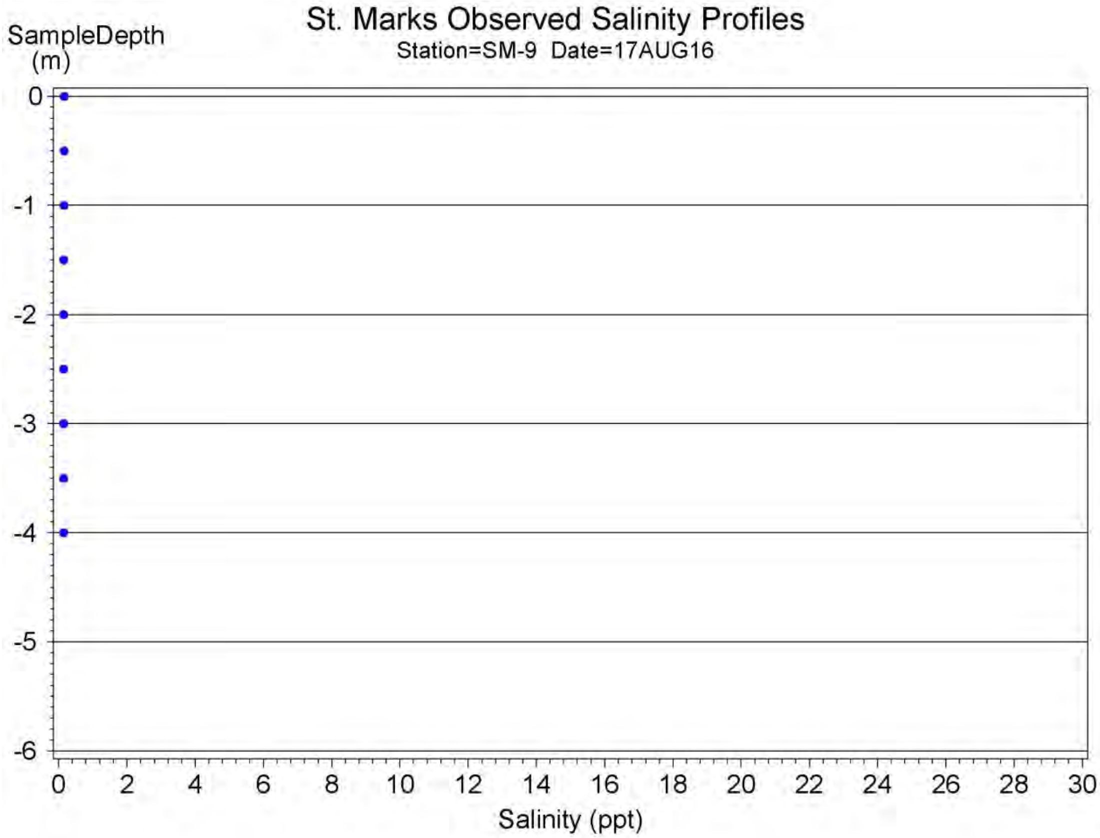
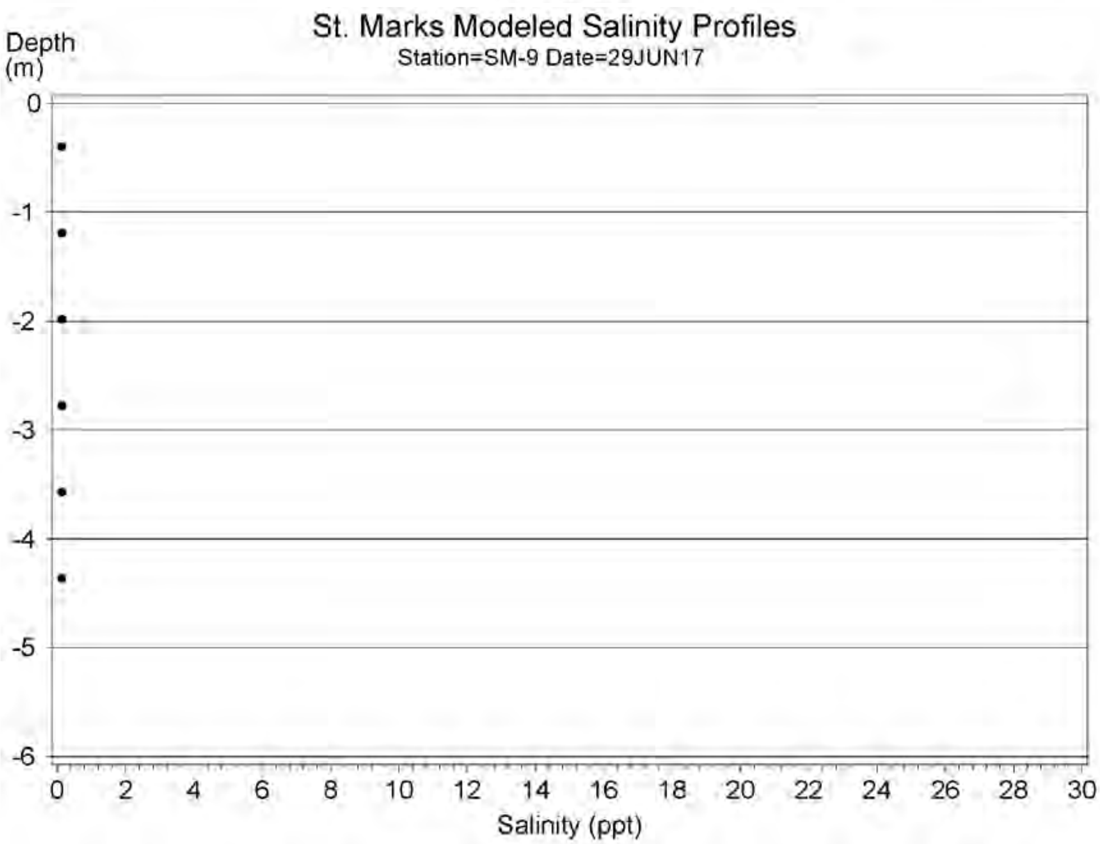
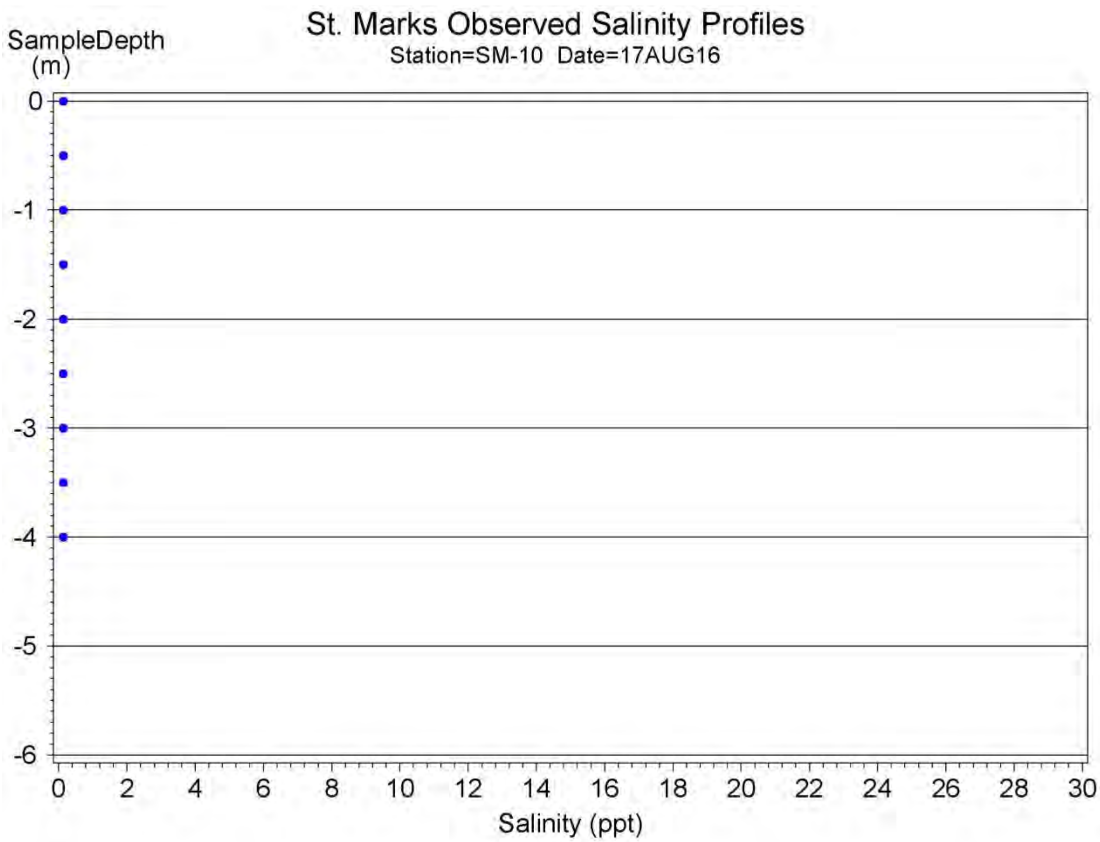
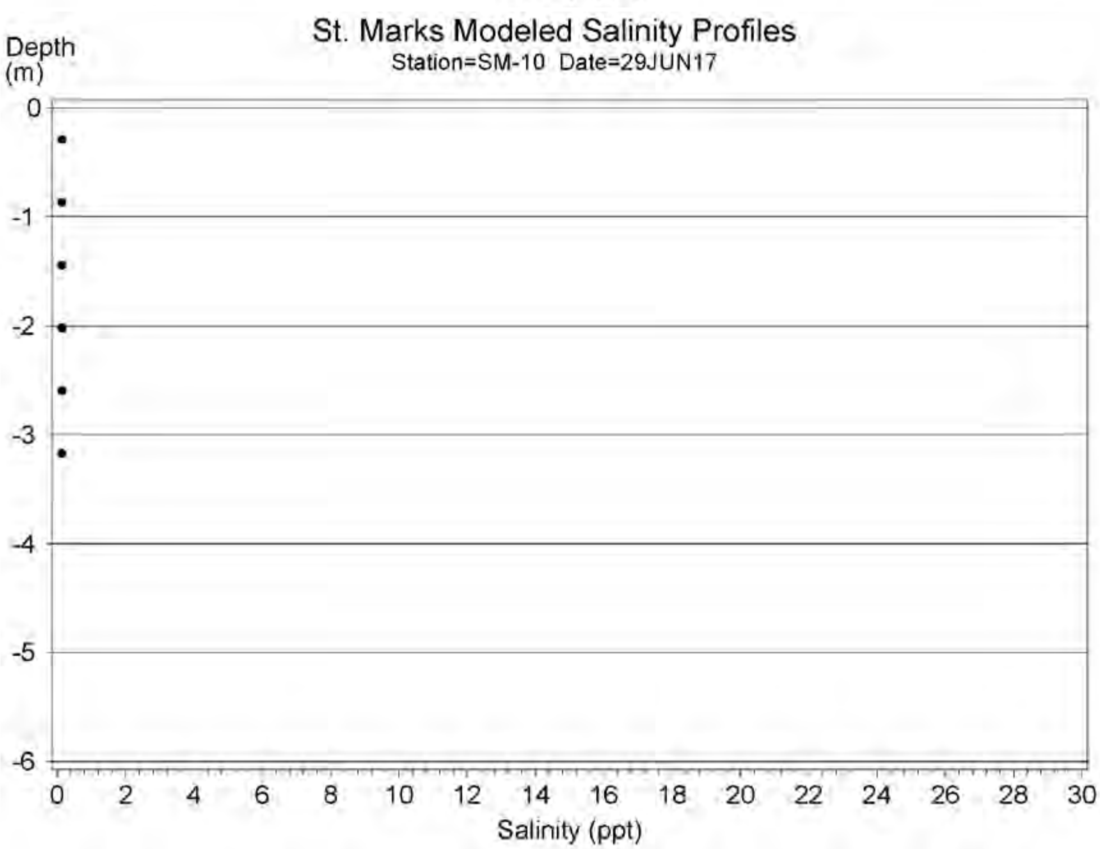
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

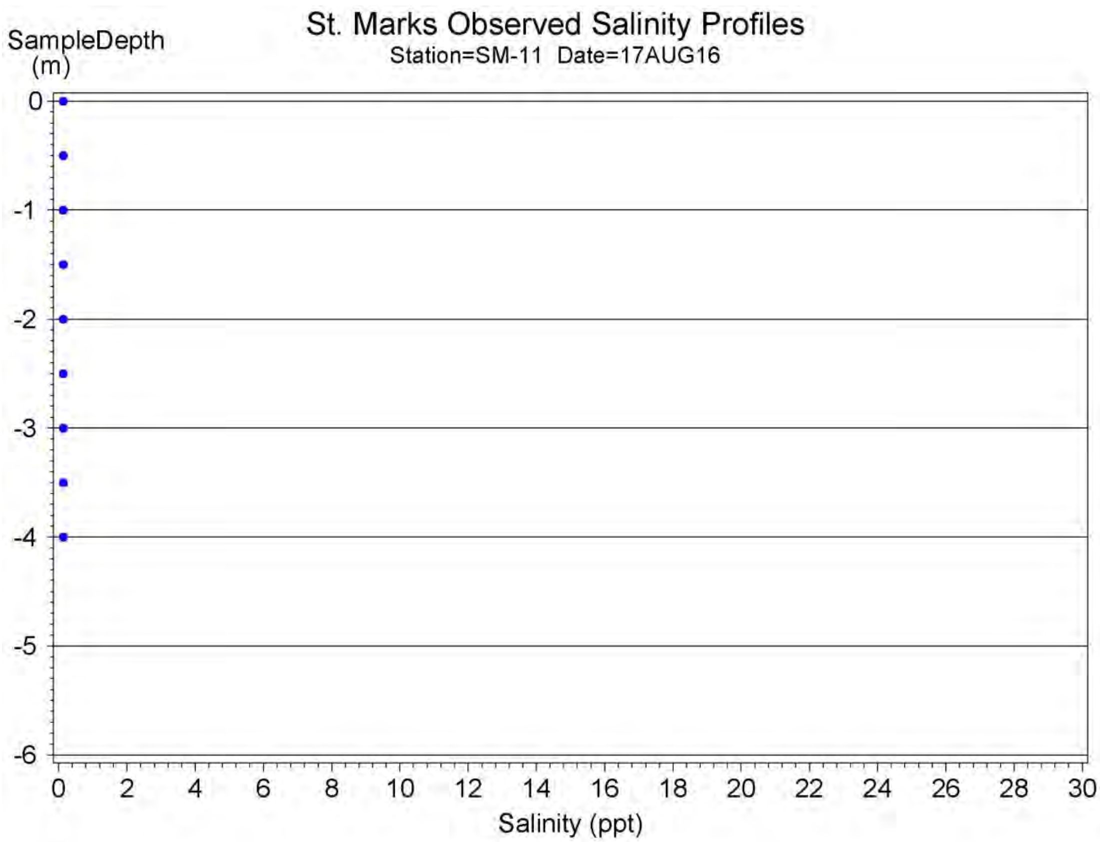

St. Marks Modeled Salinity Profiles
Station=SM-8 Date=18JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

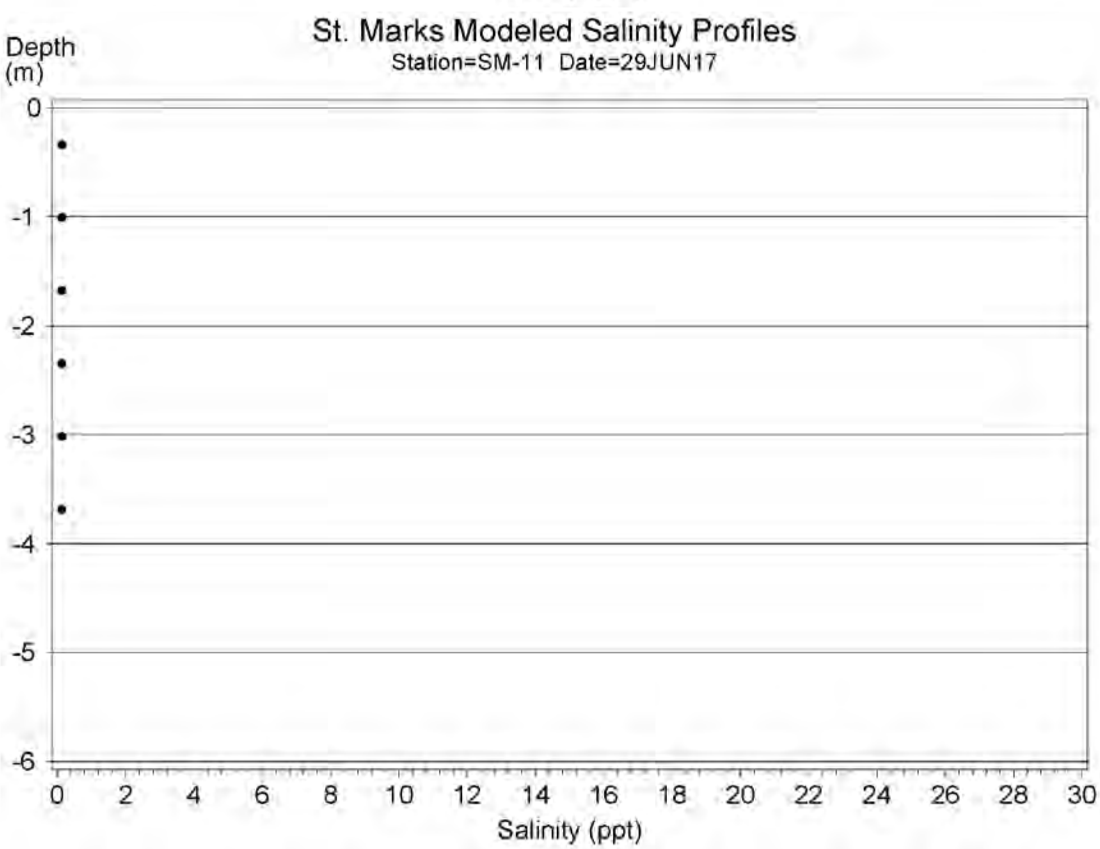

St. Marks Observed Salinity Profiles
Station=SM-9 Date=17AUG16
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

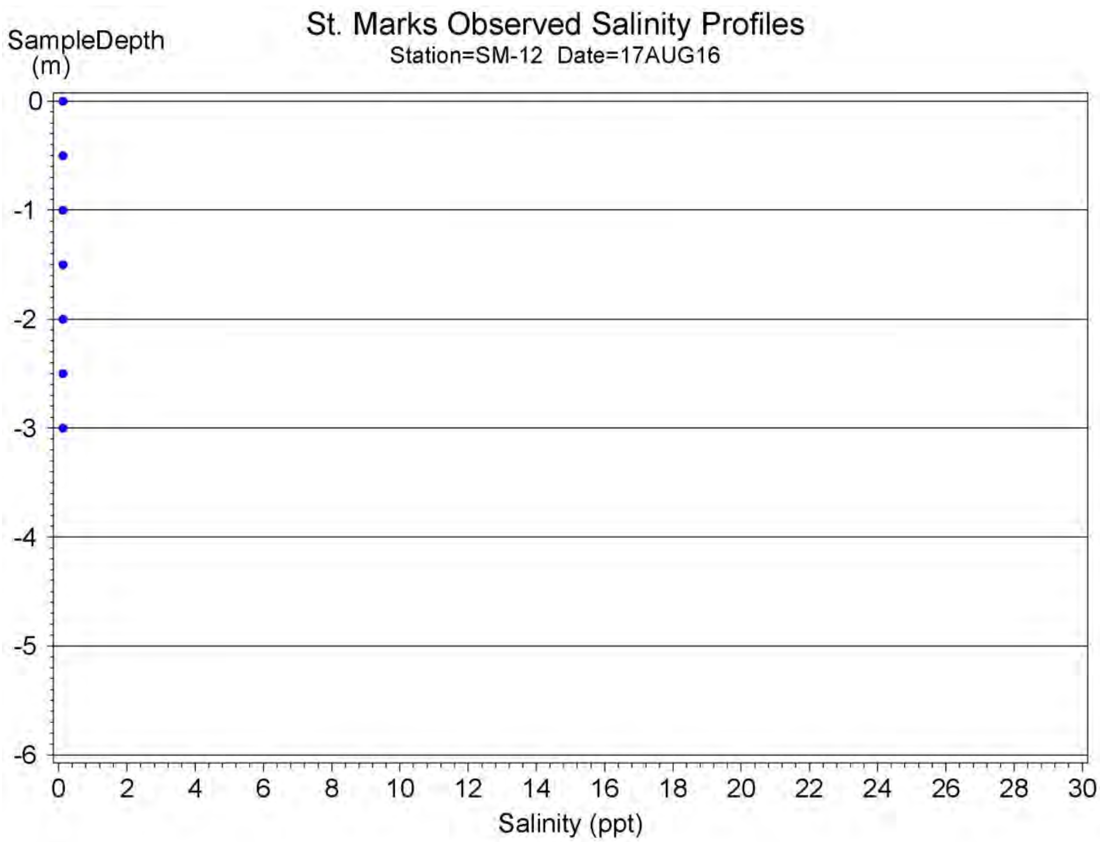

St. Marks Modeled Salinity Profiles
Station=SM-9 Date=29JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

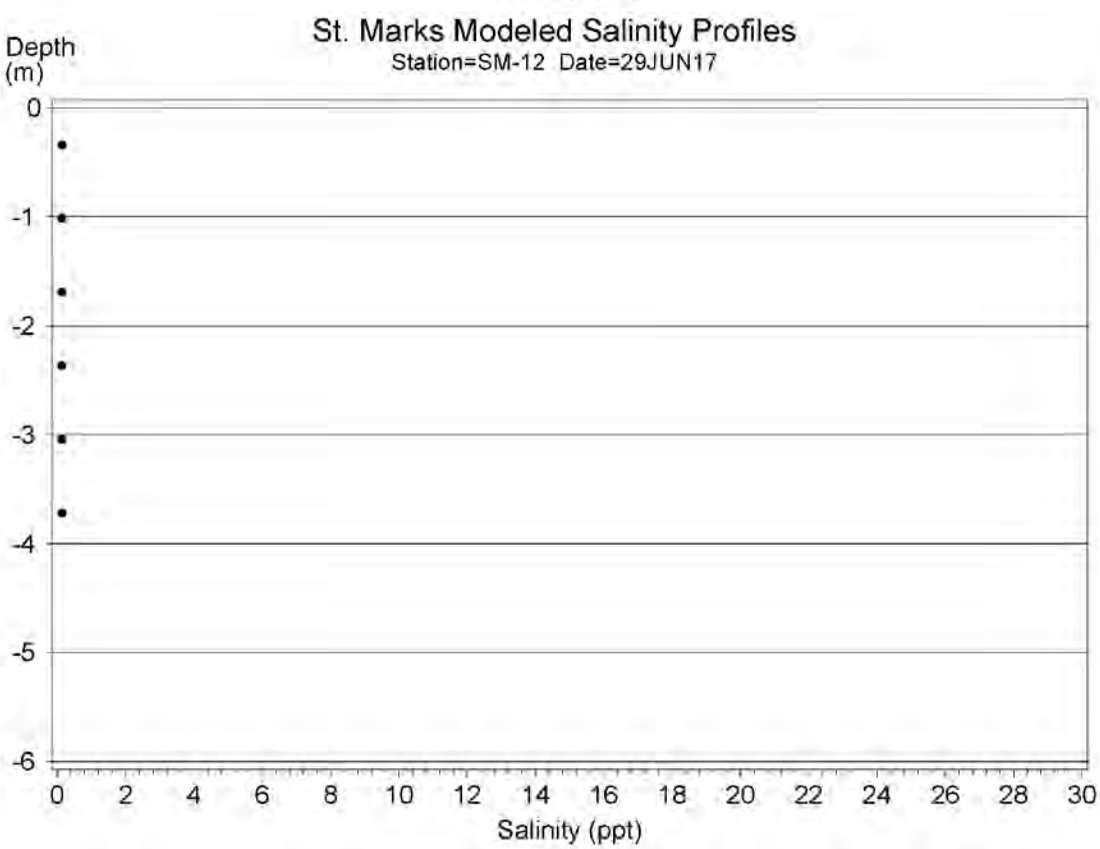

St. Marks Observed Salinity Profiles
Station=SM-10 Date=17AUG16
SampleDepth
(m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-10 Date=29JUN17
Depth
(m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-11 Date=17AUG16
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-11 Date=29JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-12 Date=17AUG16
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-12 Date=29JUN17
Depth (m)
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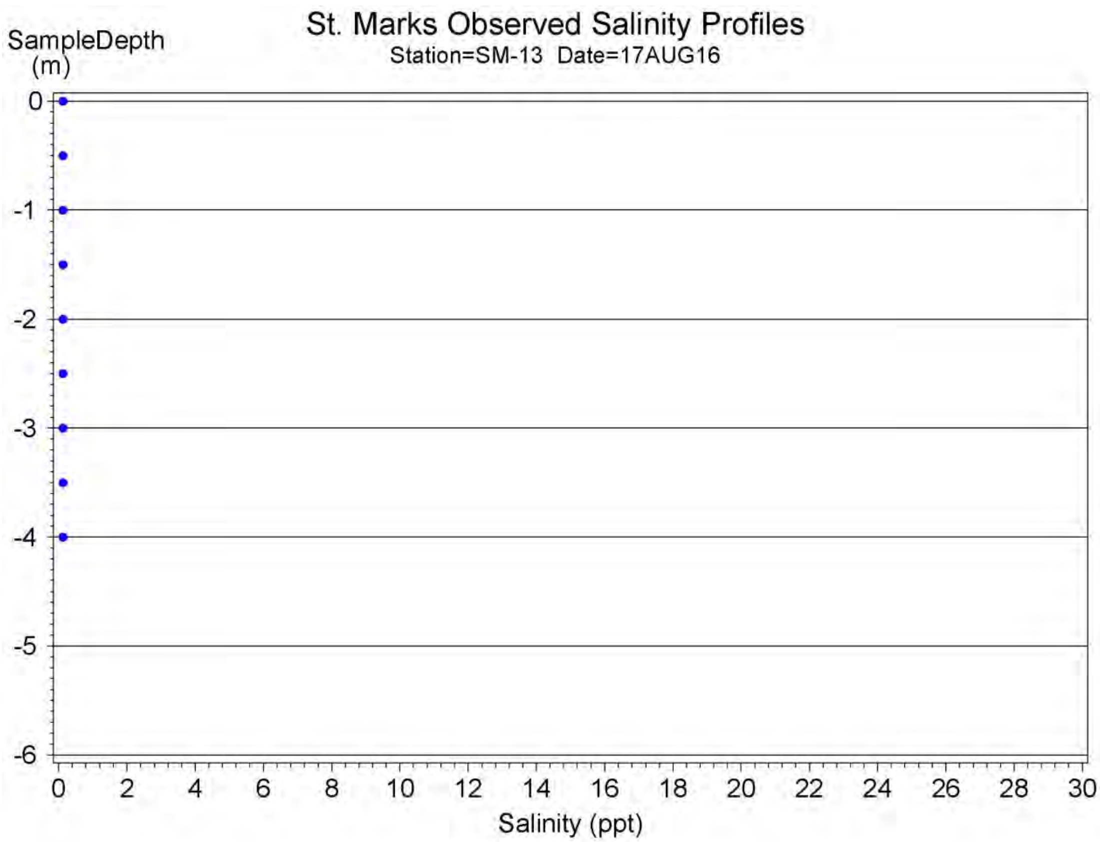
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-13 Date=17AUG16
SampleDepth (m)
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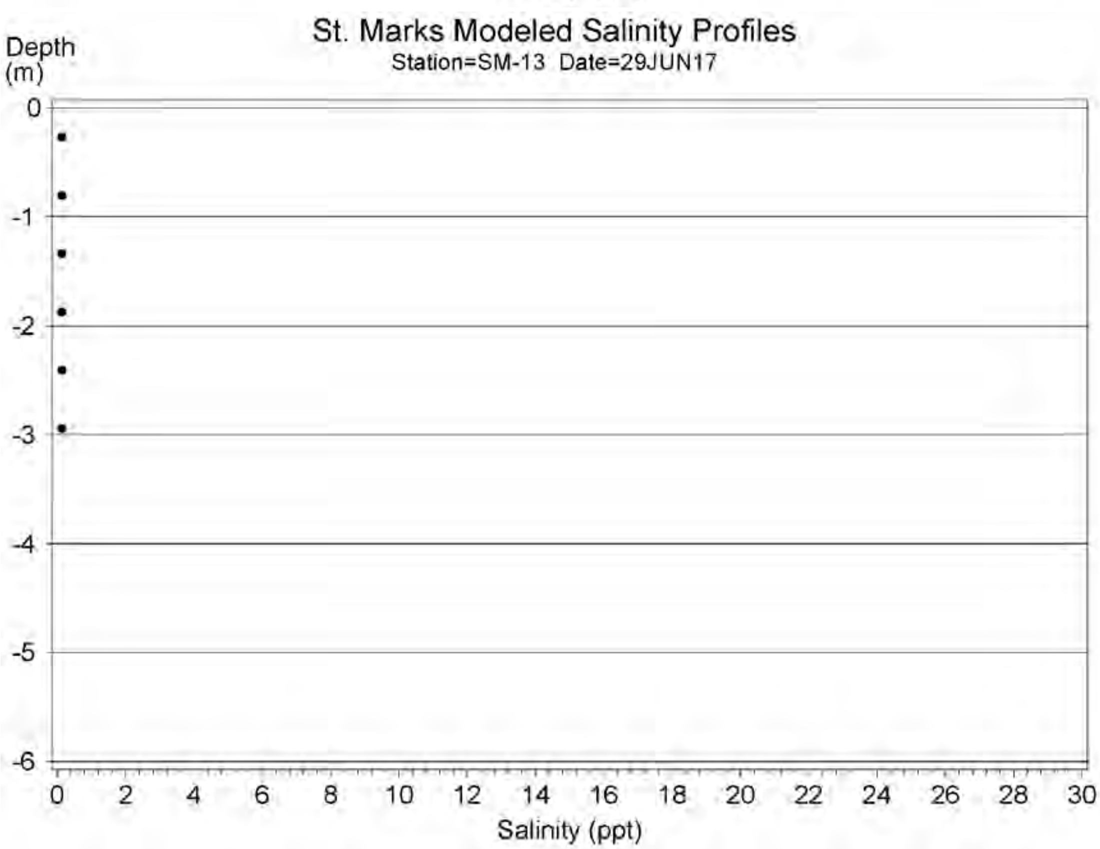
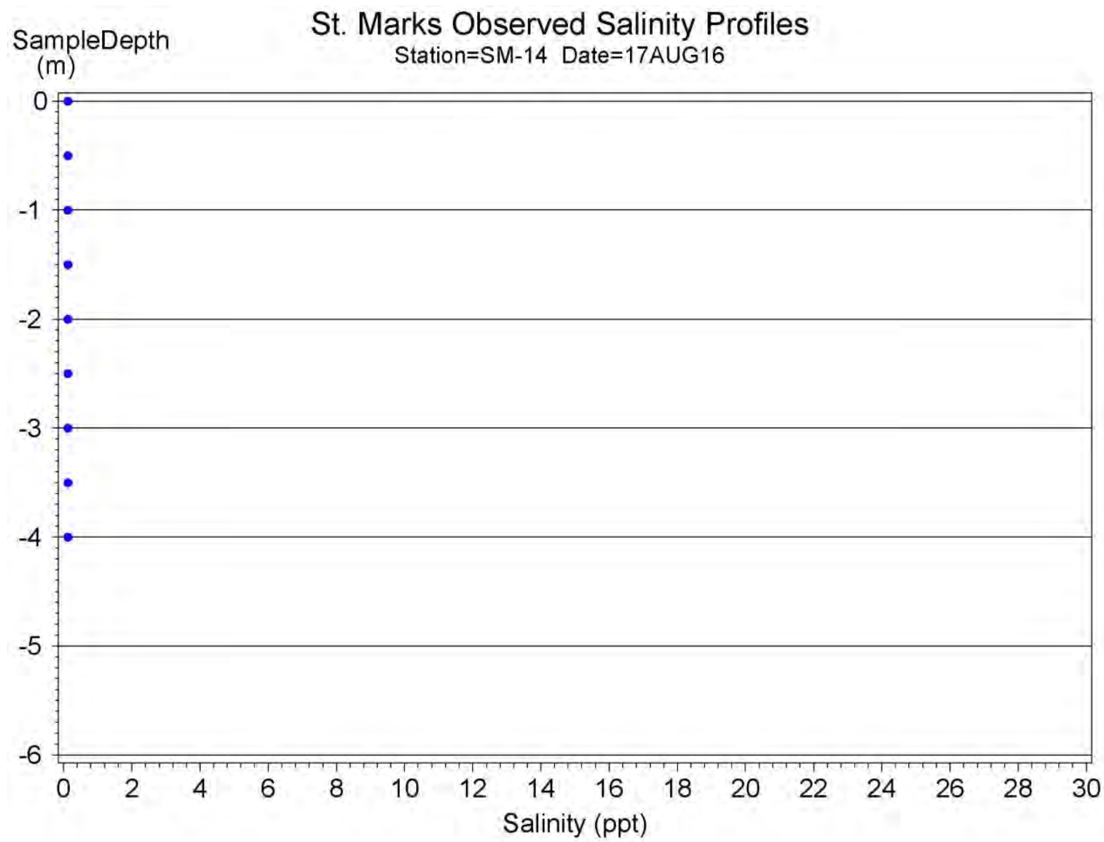
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-13 Date=29JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)



St. Marks Observed Salinity Profiles
Station=SM-14 Date=17AUG16
SampleDepth (m)
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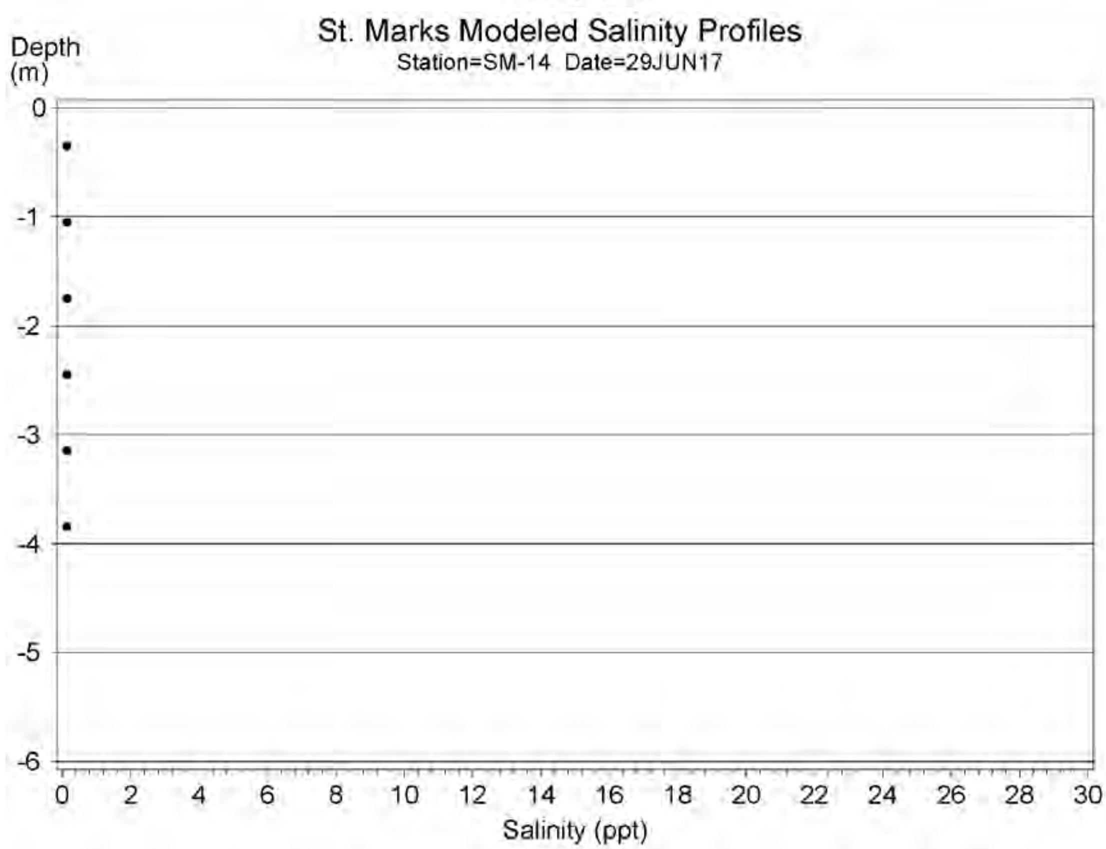
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)



St. Marks Modeled Salinity Profiles
Station=SM-14 Date=29JUN17
Depth (m)
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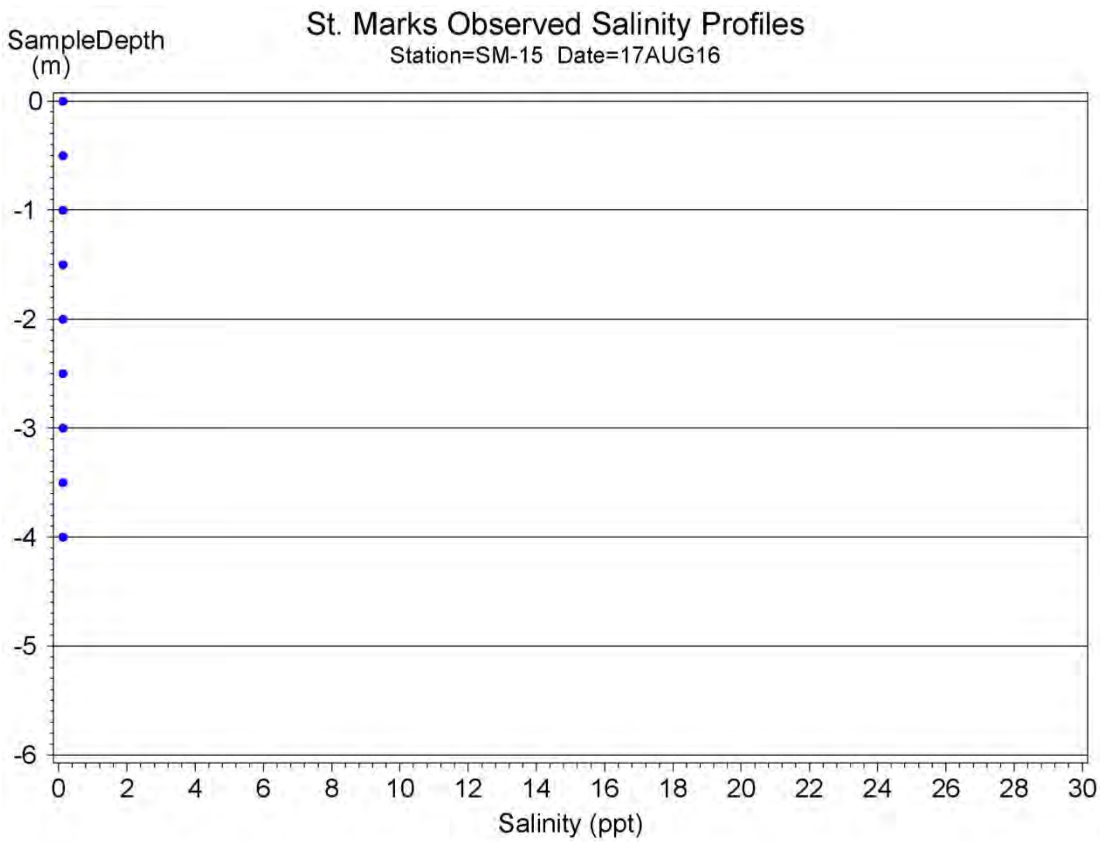
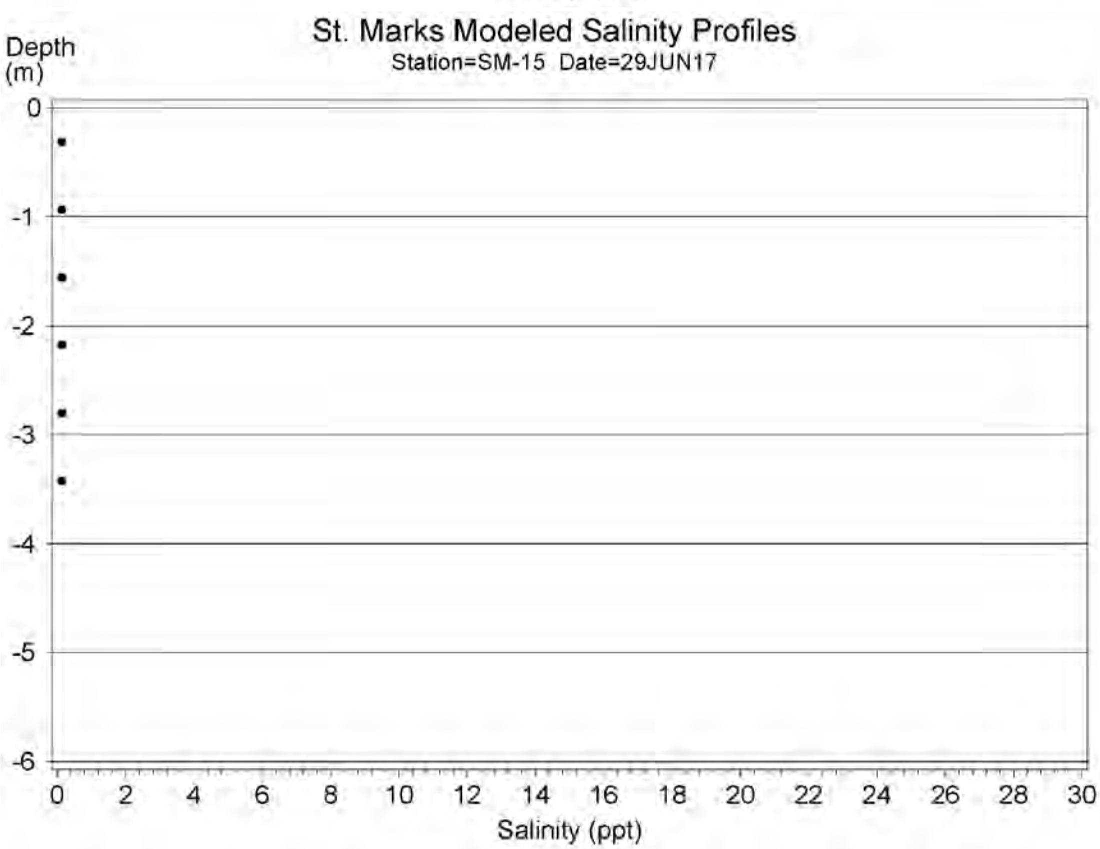
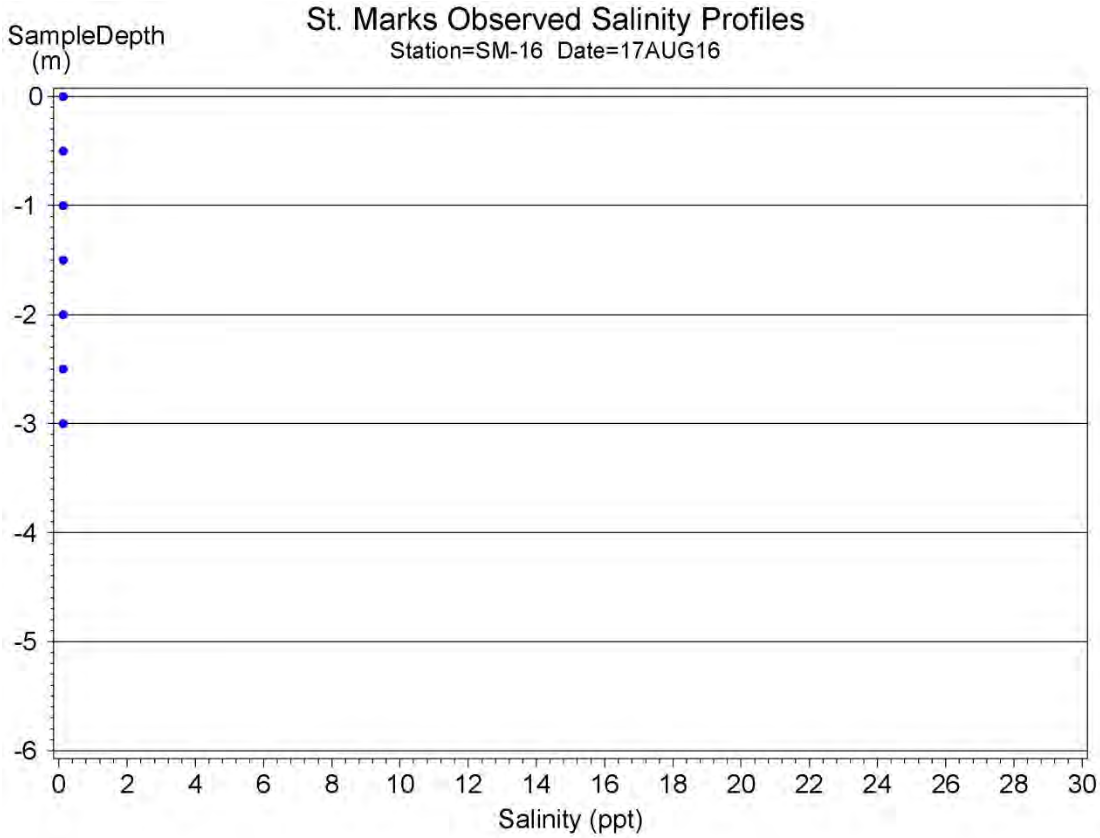
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-15 Date=17AUG16
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-15 Date=29JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-16 Date=17AUG16
SampleDepth (m)
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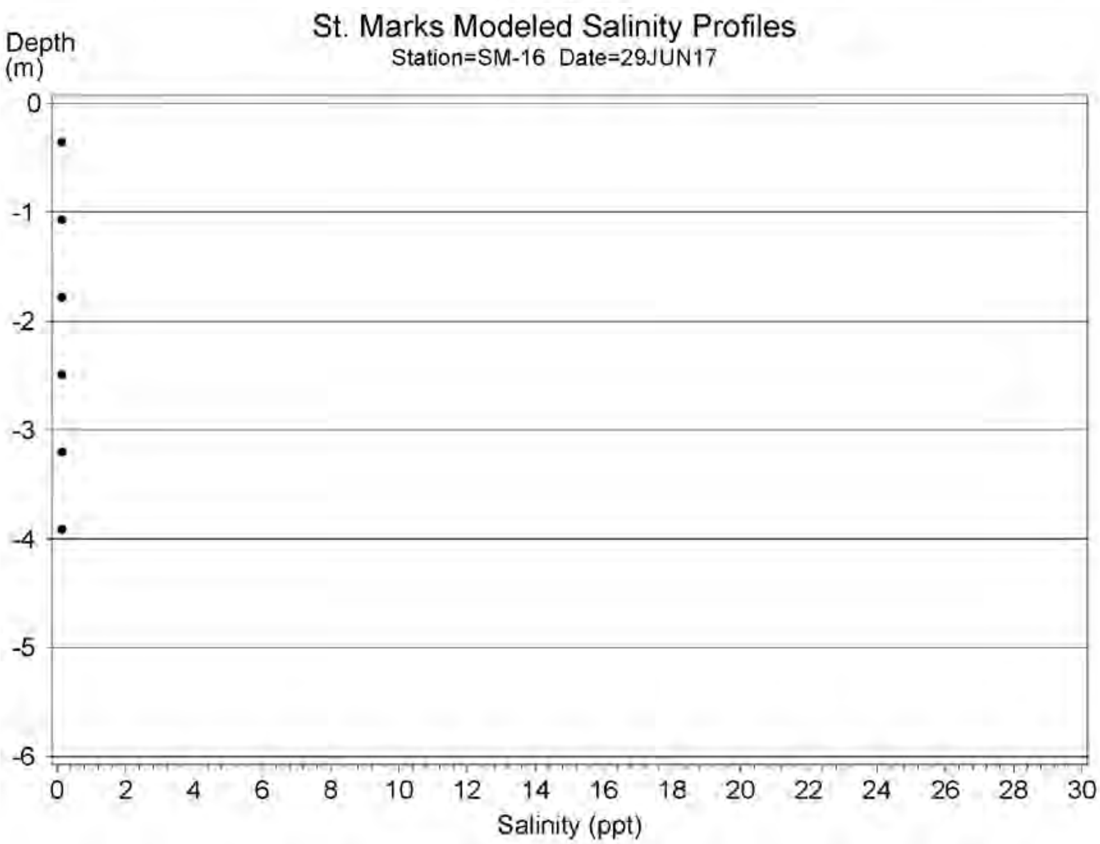
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-16 Date=29JUN17
Depth (m)
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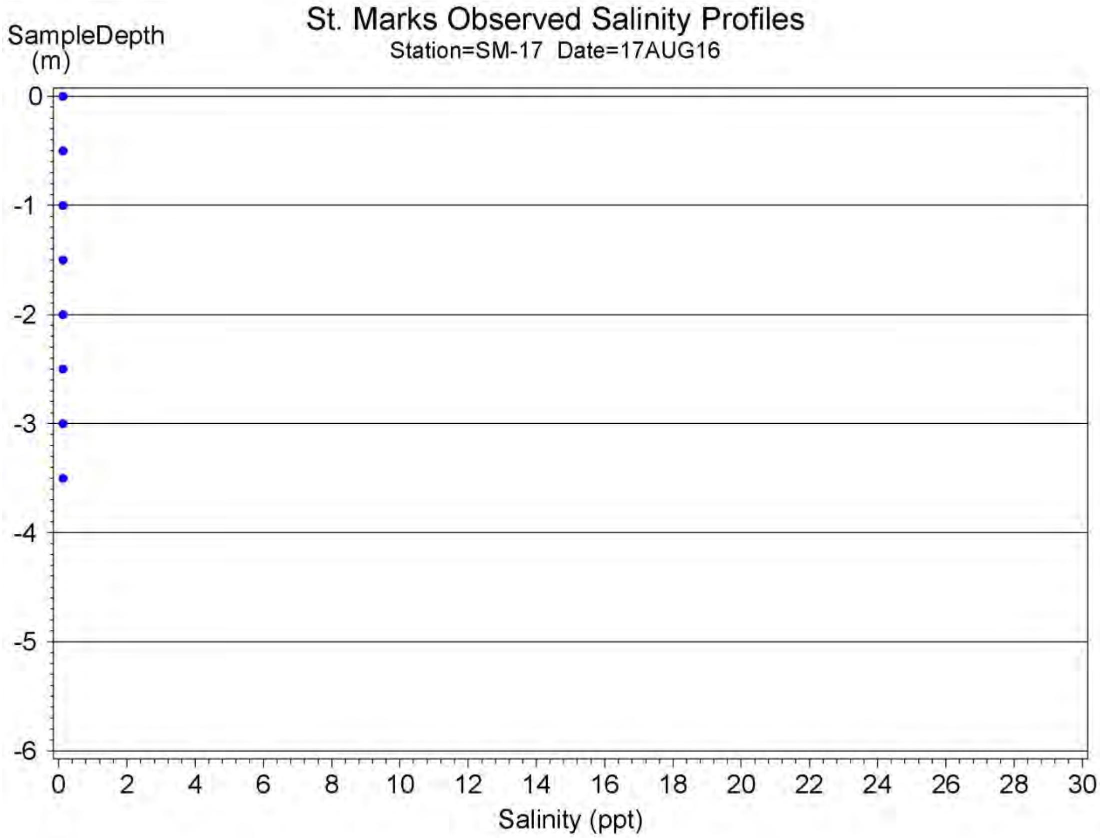
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-17 Date=17AUG16
SampleDepth (m)
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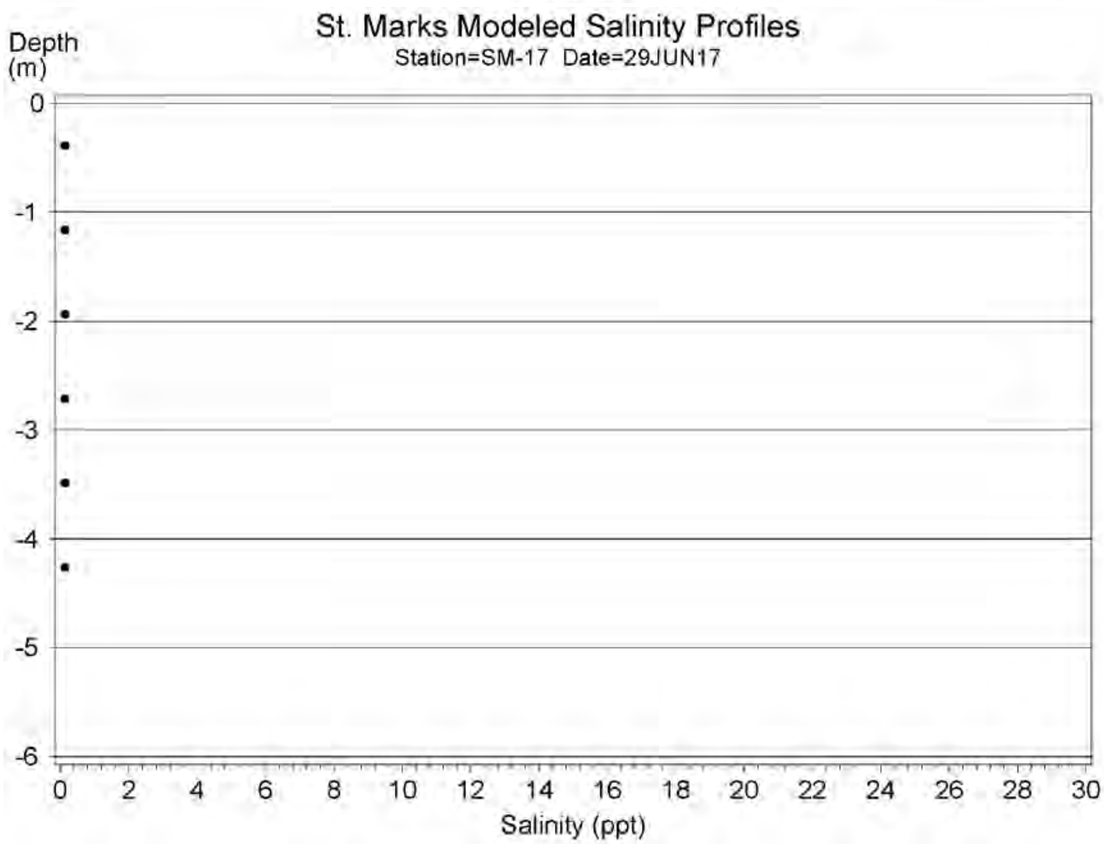
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-17 Date=29JUN17
Depth (m)
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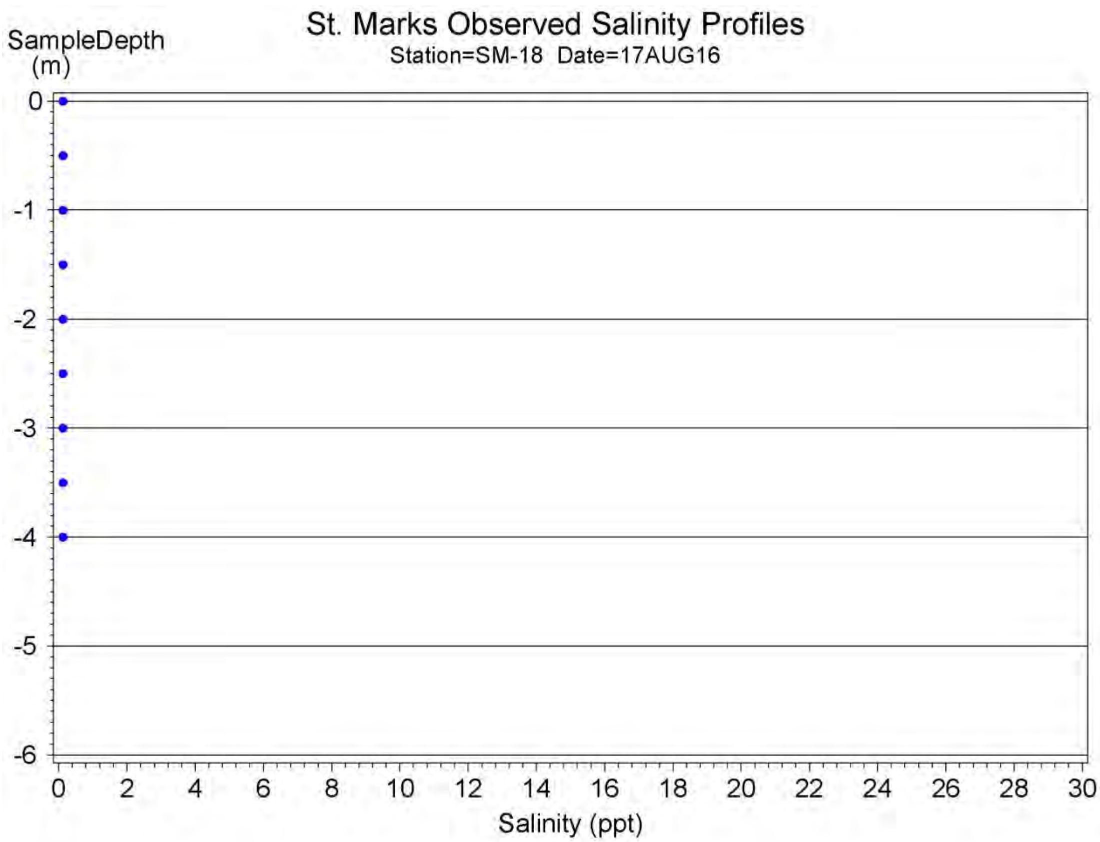
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-18 Date=17AUG16
SampleDepth (m)
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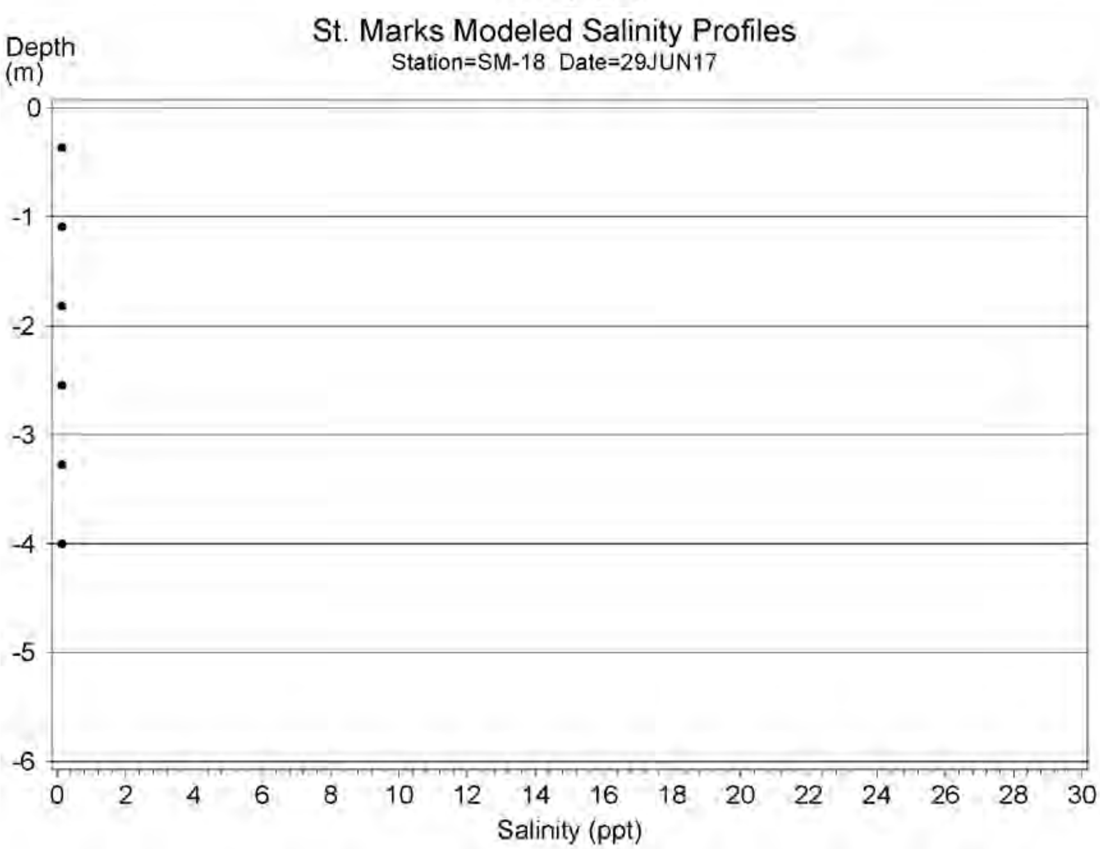
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-18 Date=29JUN17
Depth (m)
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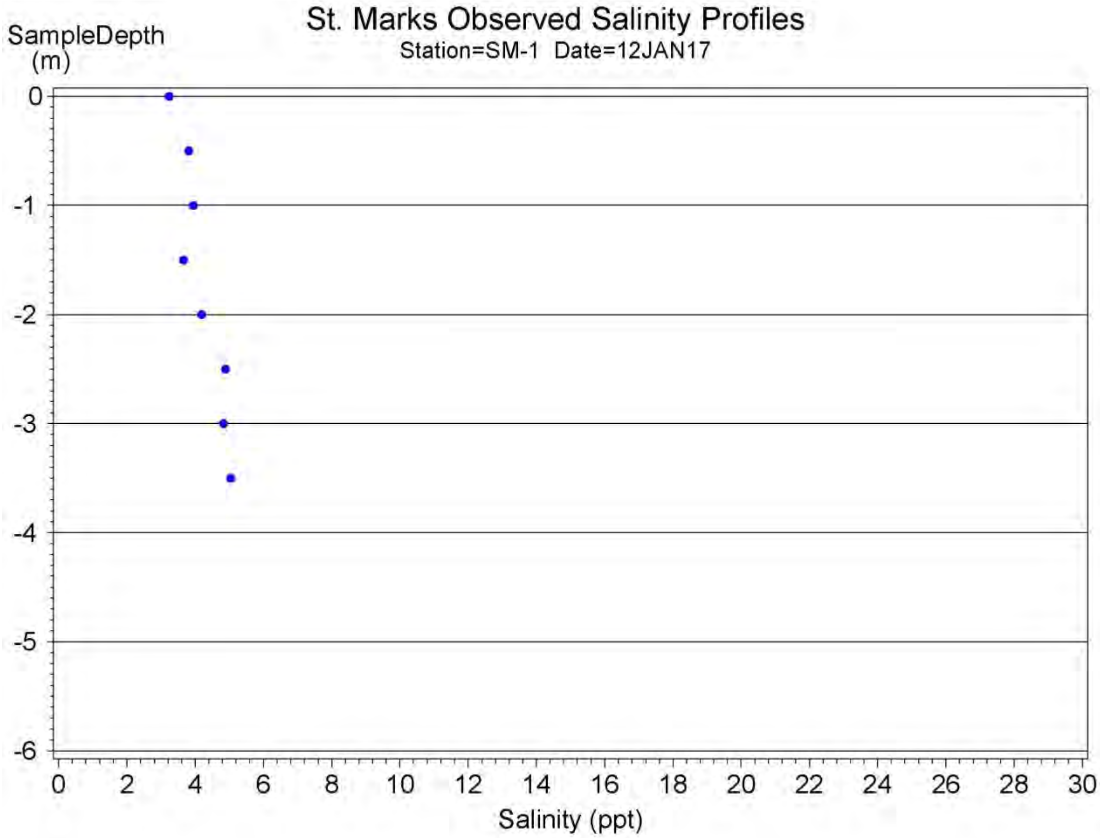
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-1 Date=12JAN17
SampleDepth (m)
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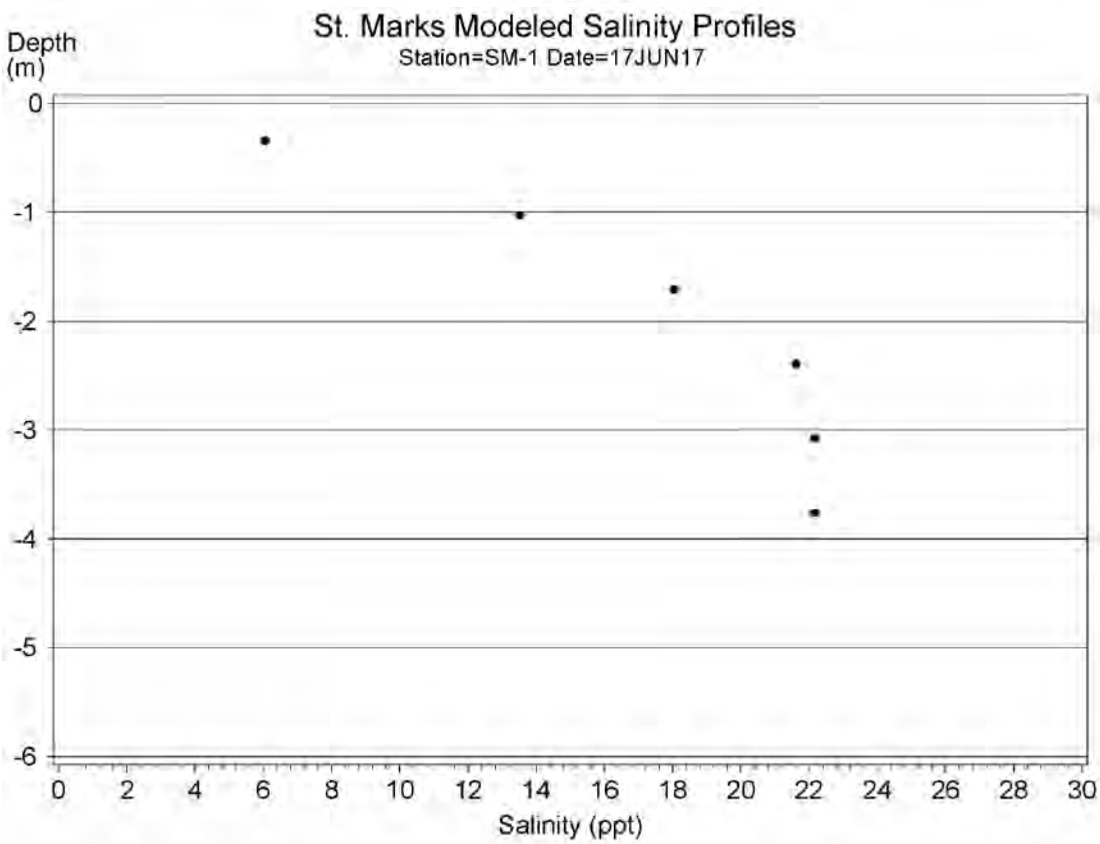
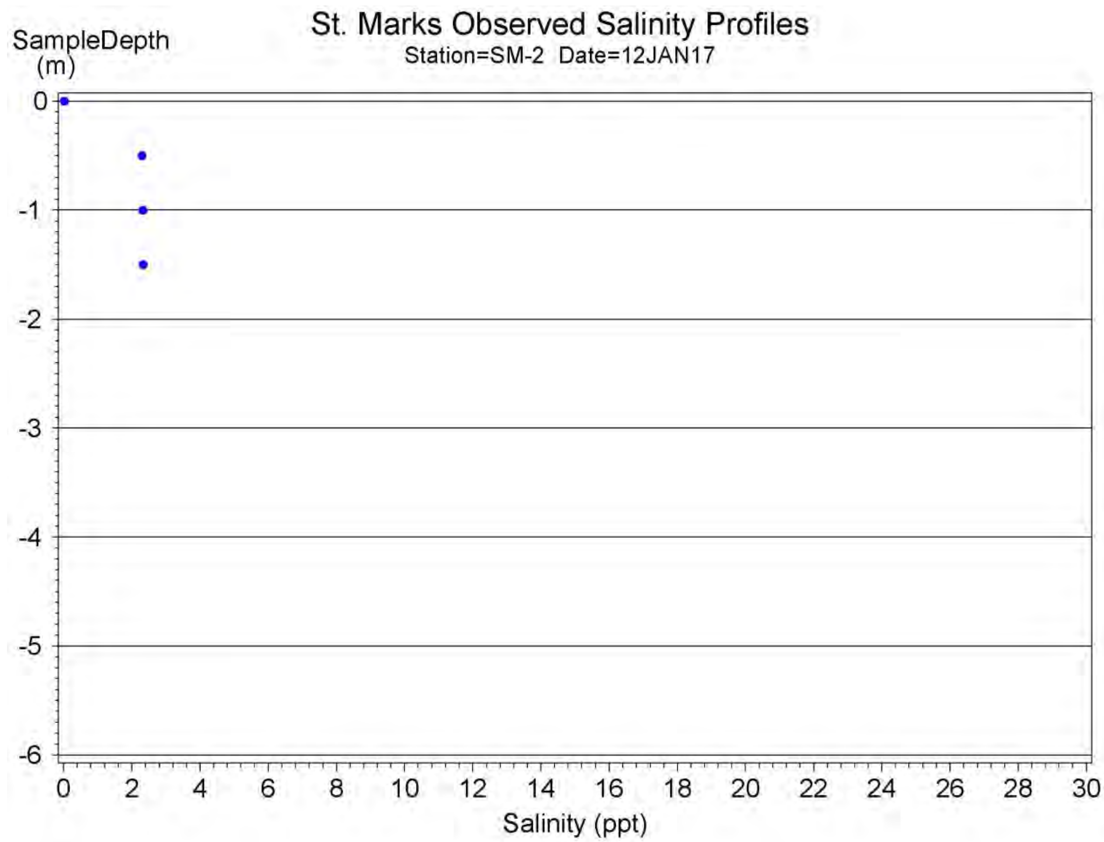
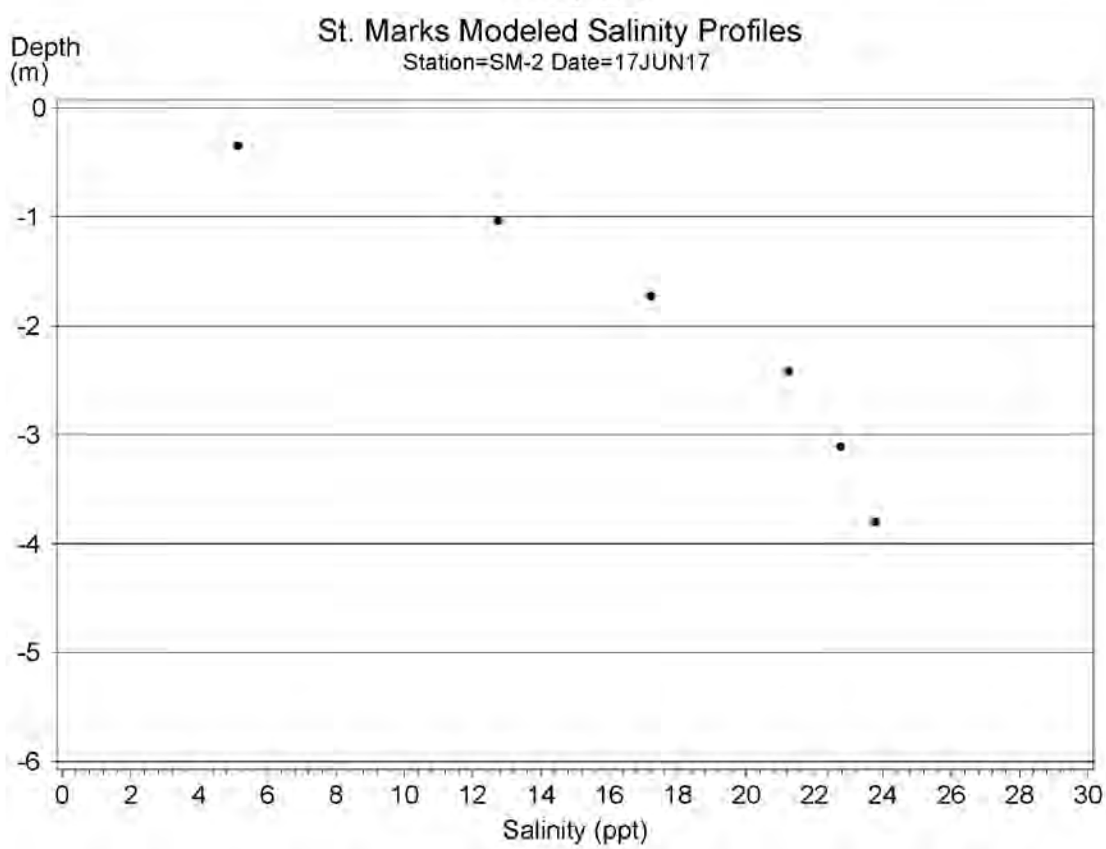
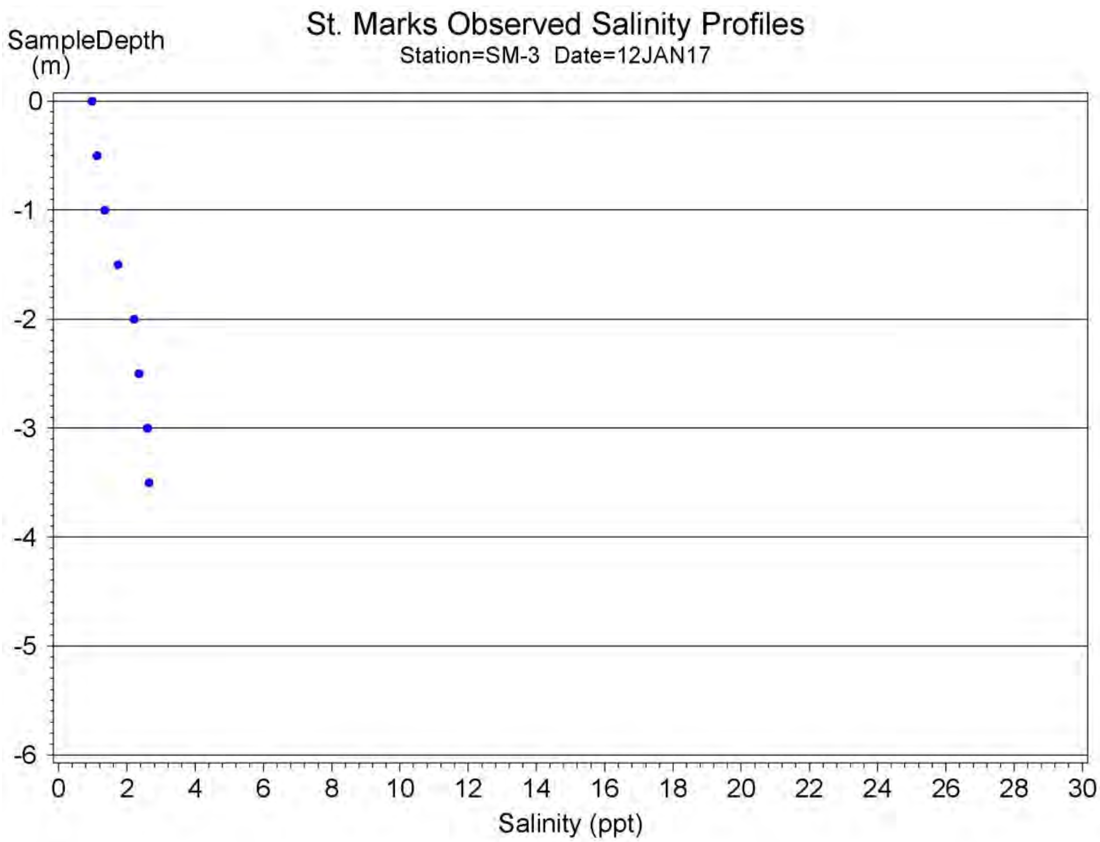
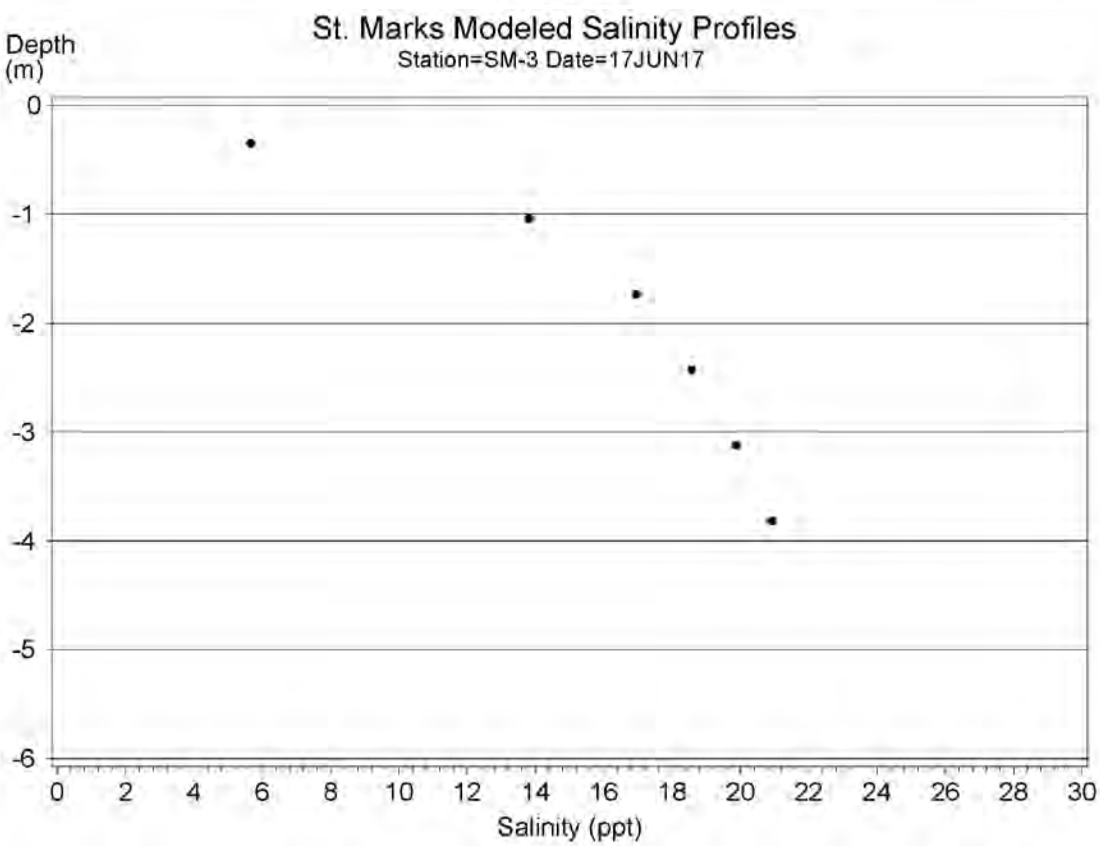
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

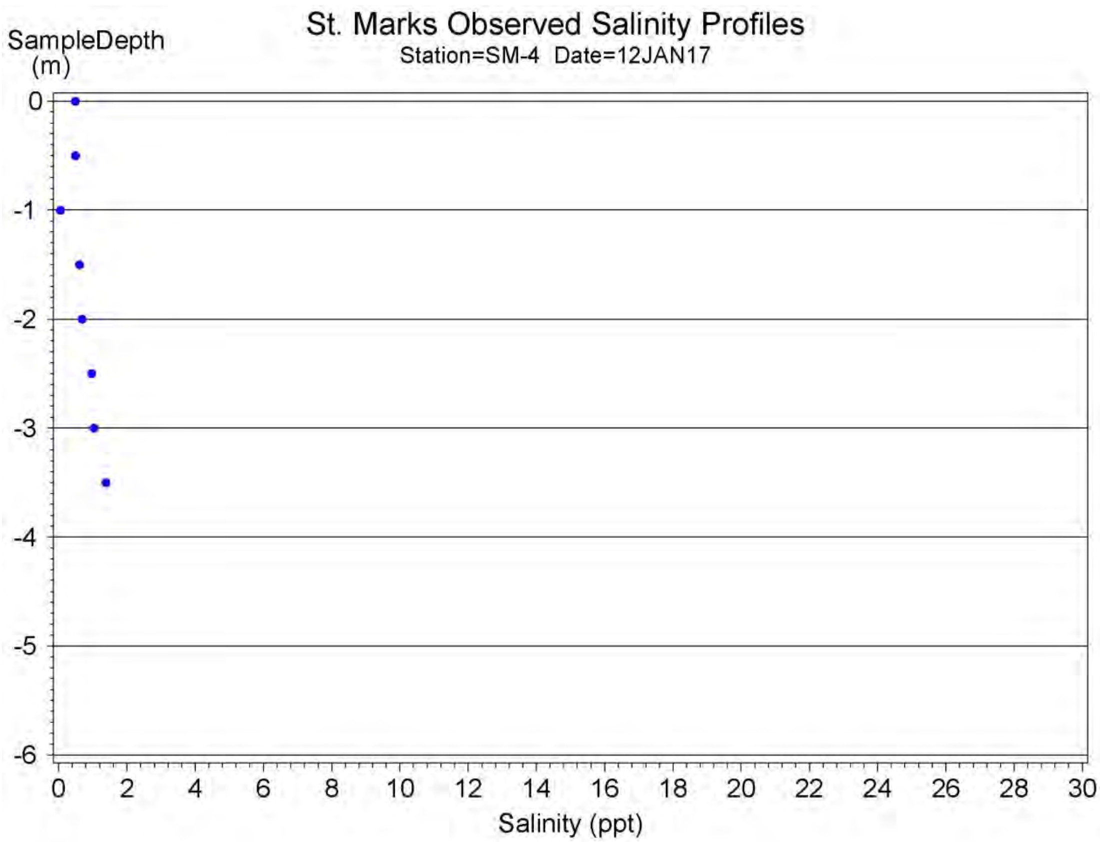

St. Marks Modeled Salinity Profiles
Station=SM-1 Date=17JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-2 Date=12JAN17
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

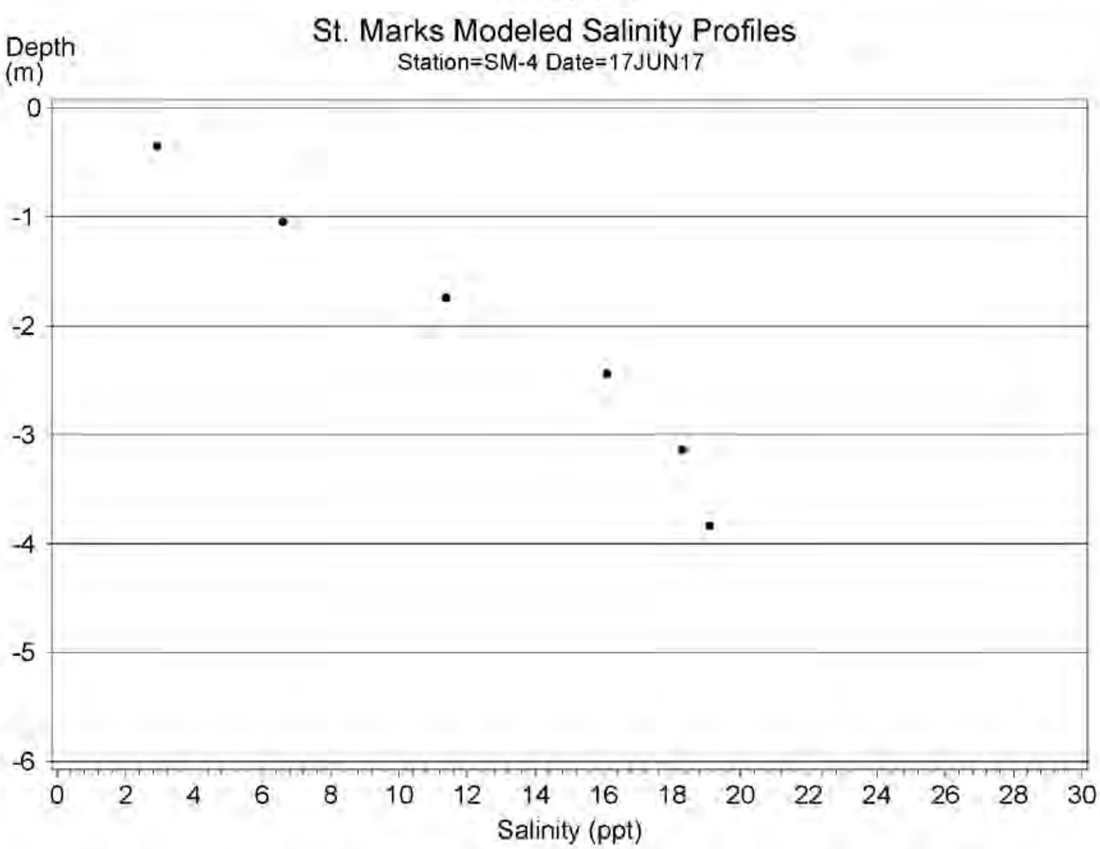

St. Marks Modeled Salinity Profiles
Station=SM-2 Date=17JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-3 Date=12JAN17
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

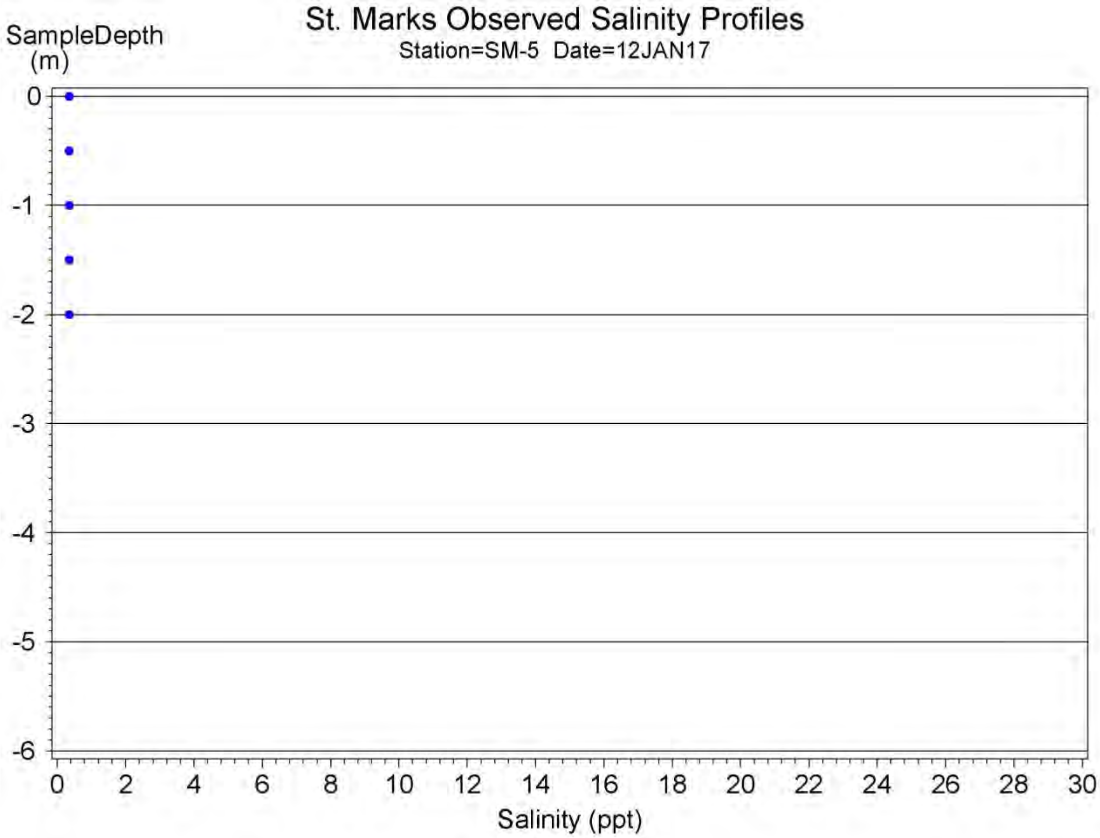

St. Marks Modeled Salinity Profiles
Station=SM-3 Date=17JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

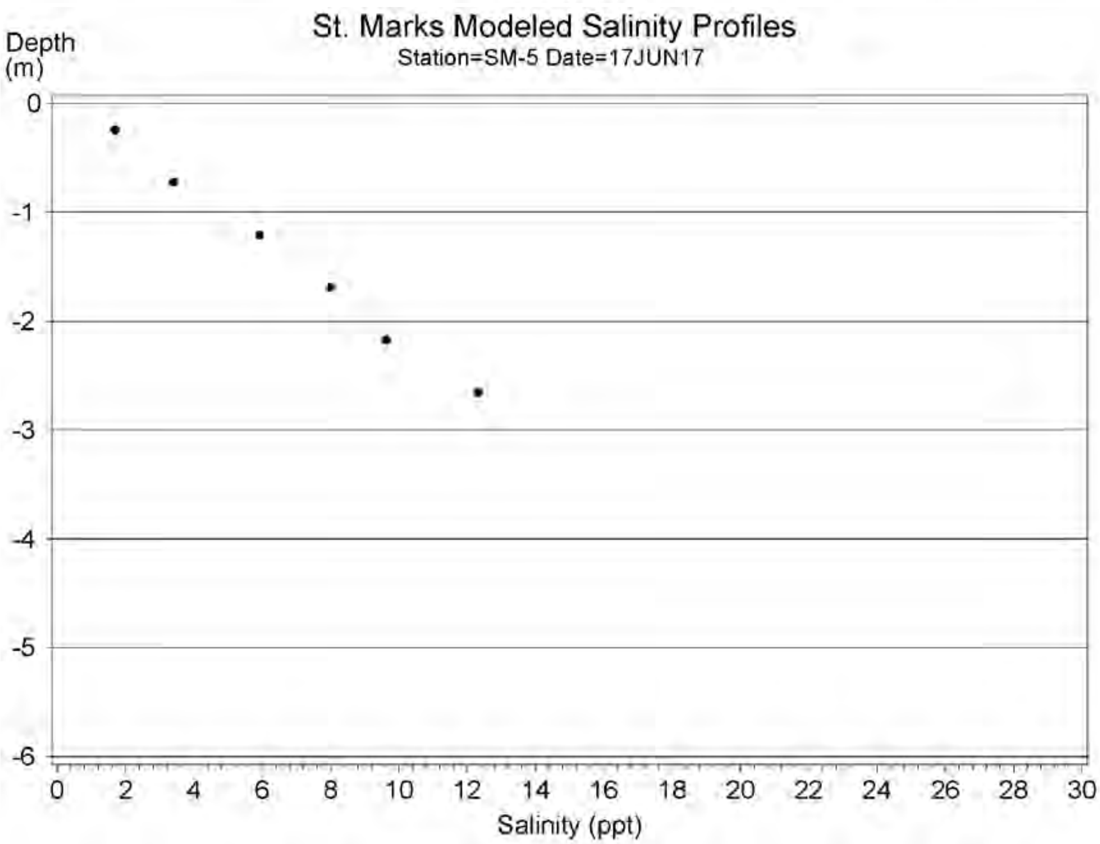


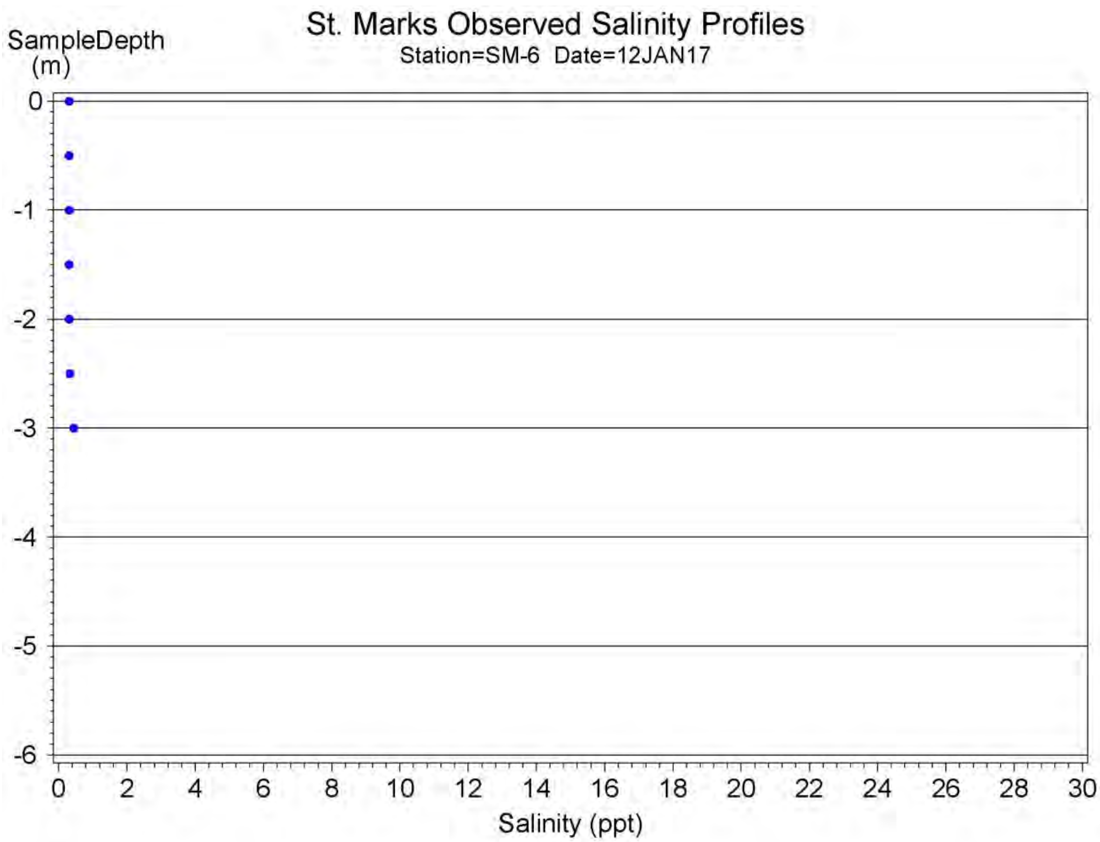
St. Marks Observed Salinity Profiles
Station=SM-4 Date=12JAN17
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)



St. Marks Modeled Salinity Profiles
Station=SM-4 Date=17JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-5 Date=12JAN17
SampleDepth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-5 Date=17JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-6 Date=12JAN17
SampleDepth (m)
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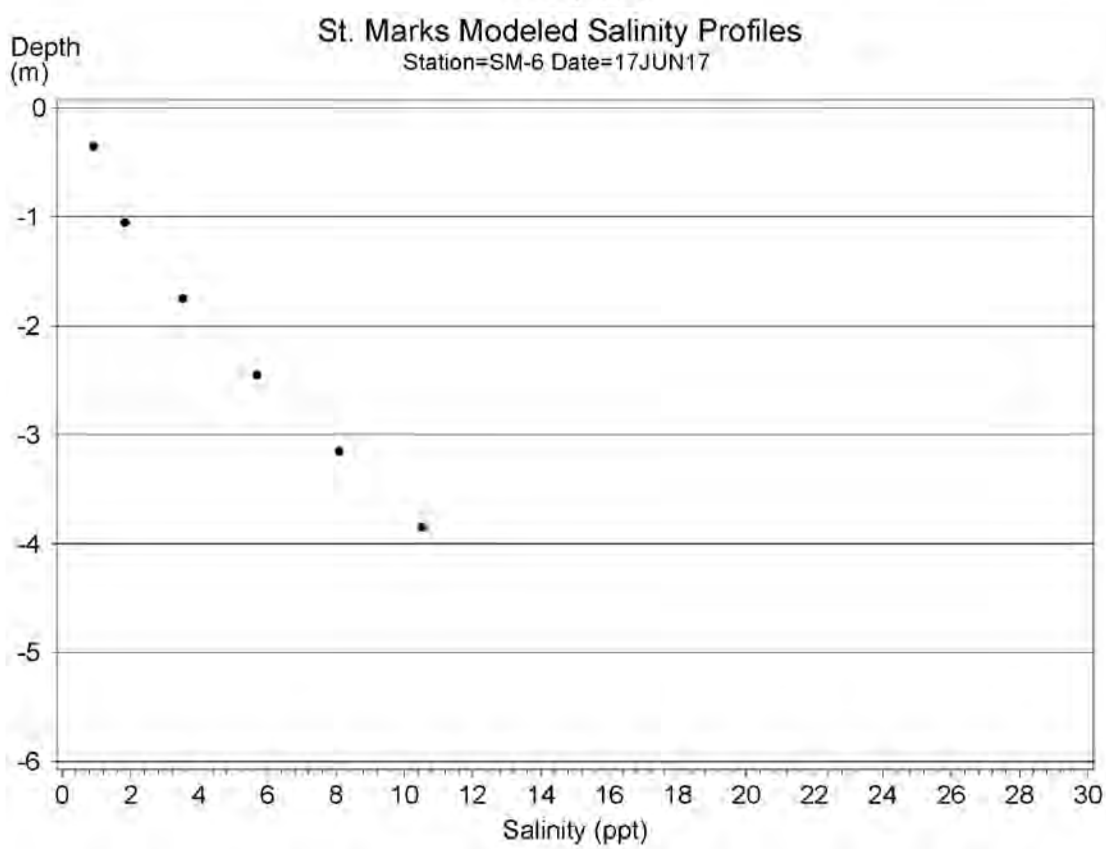
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-6 Date=17JUN17
Depth (m)
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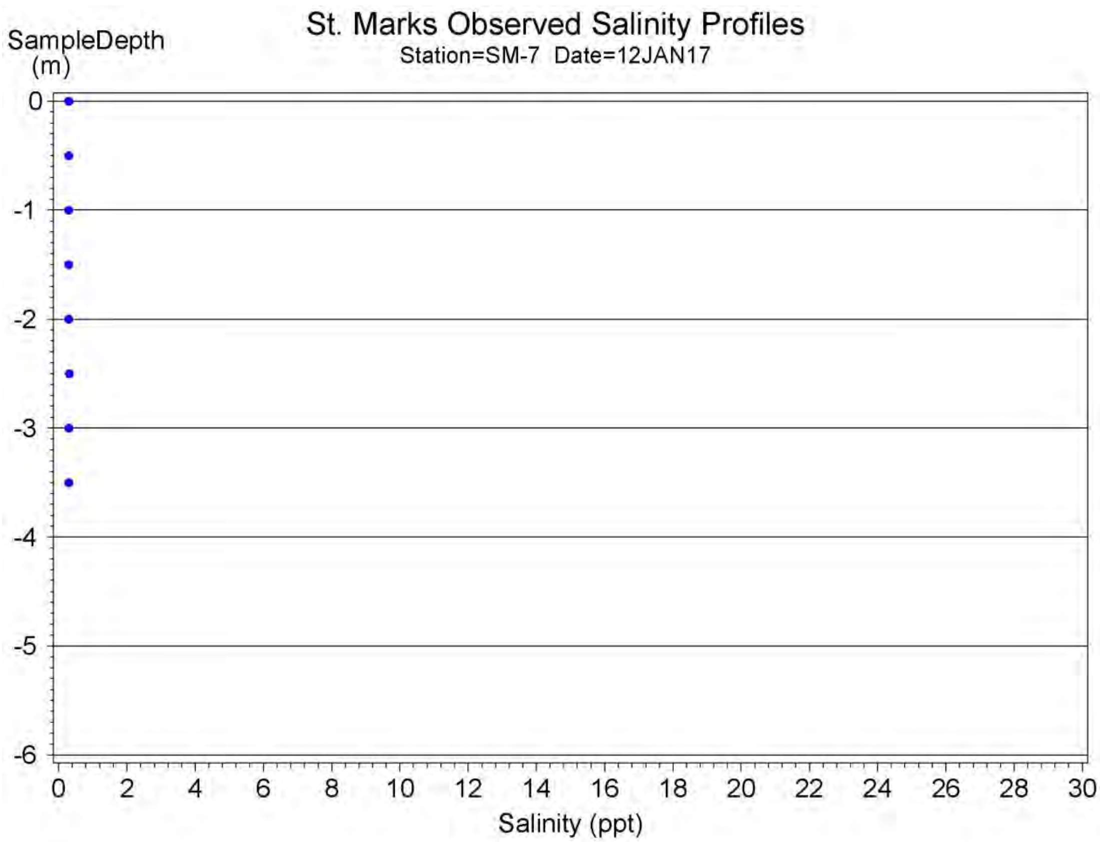
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-7 Date=12JAN17
SampleDepth (m)
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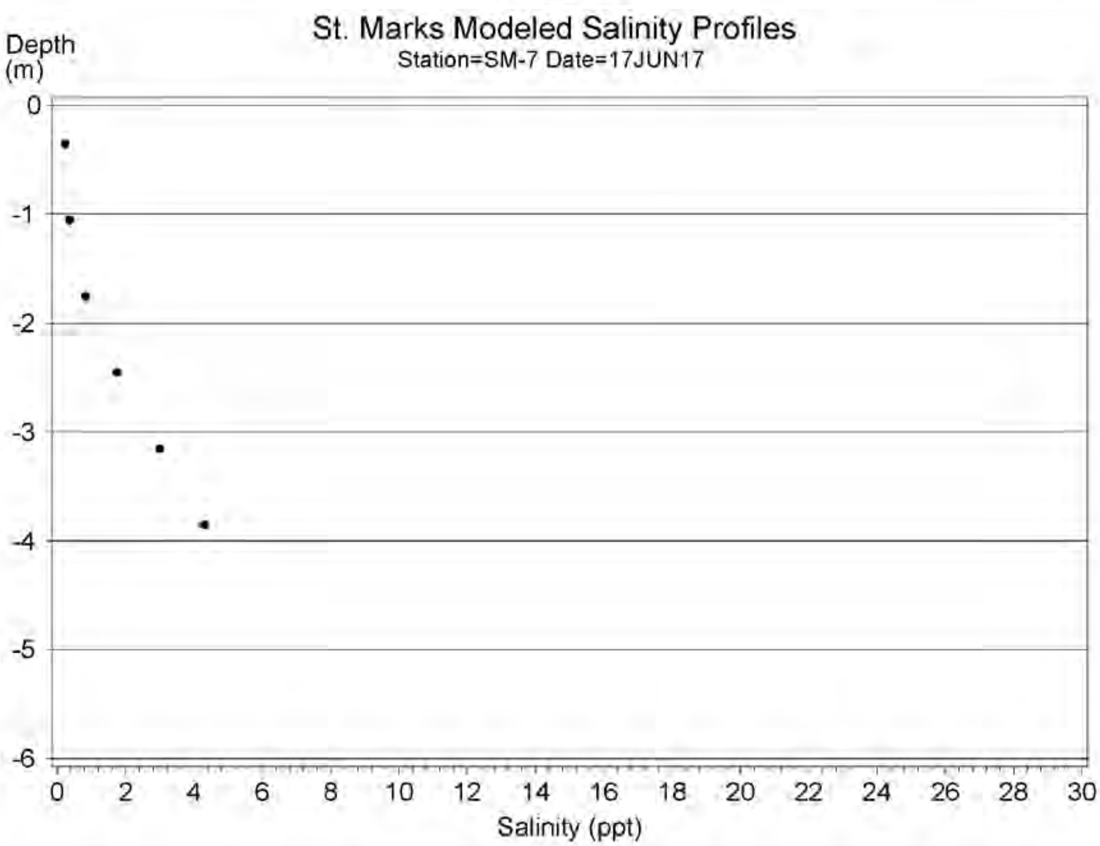
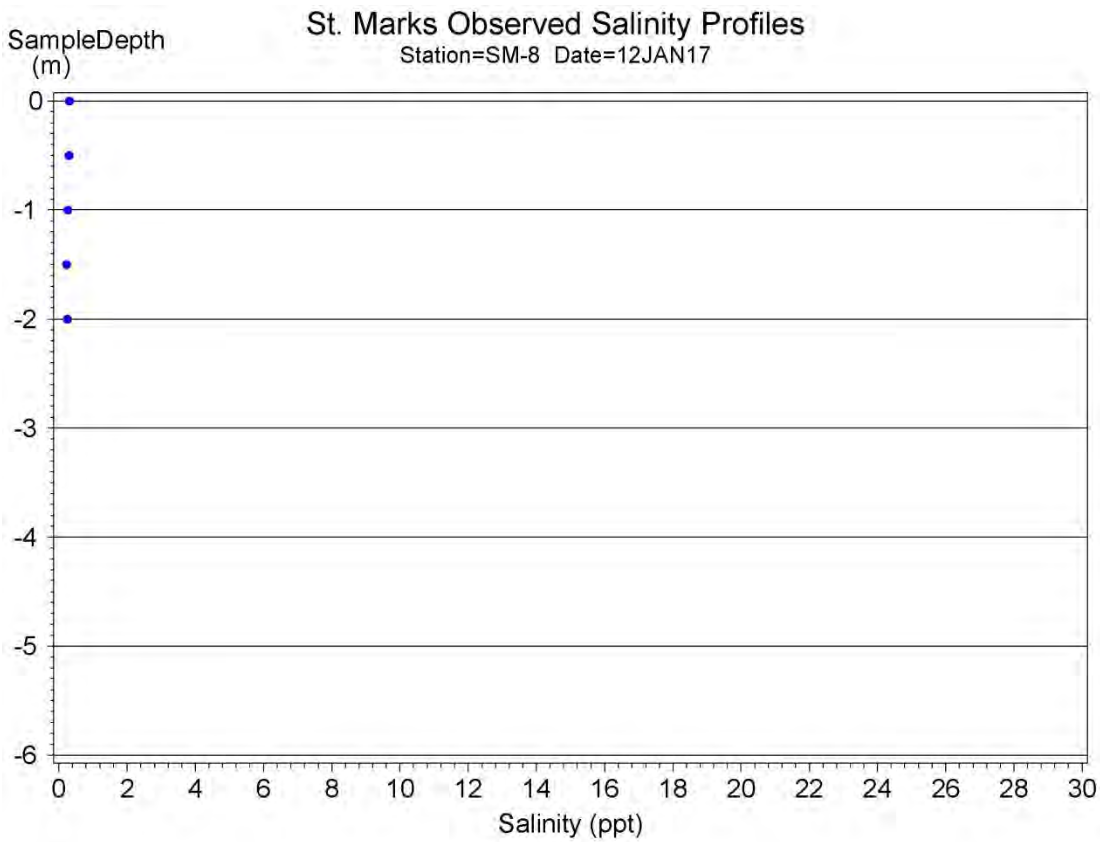
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-7 Date=17JUN17
Depth (m)
0
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-8 Date=12JAN17
SampleDepth (m)
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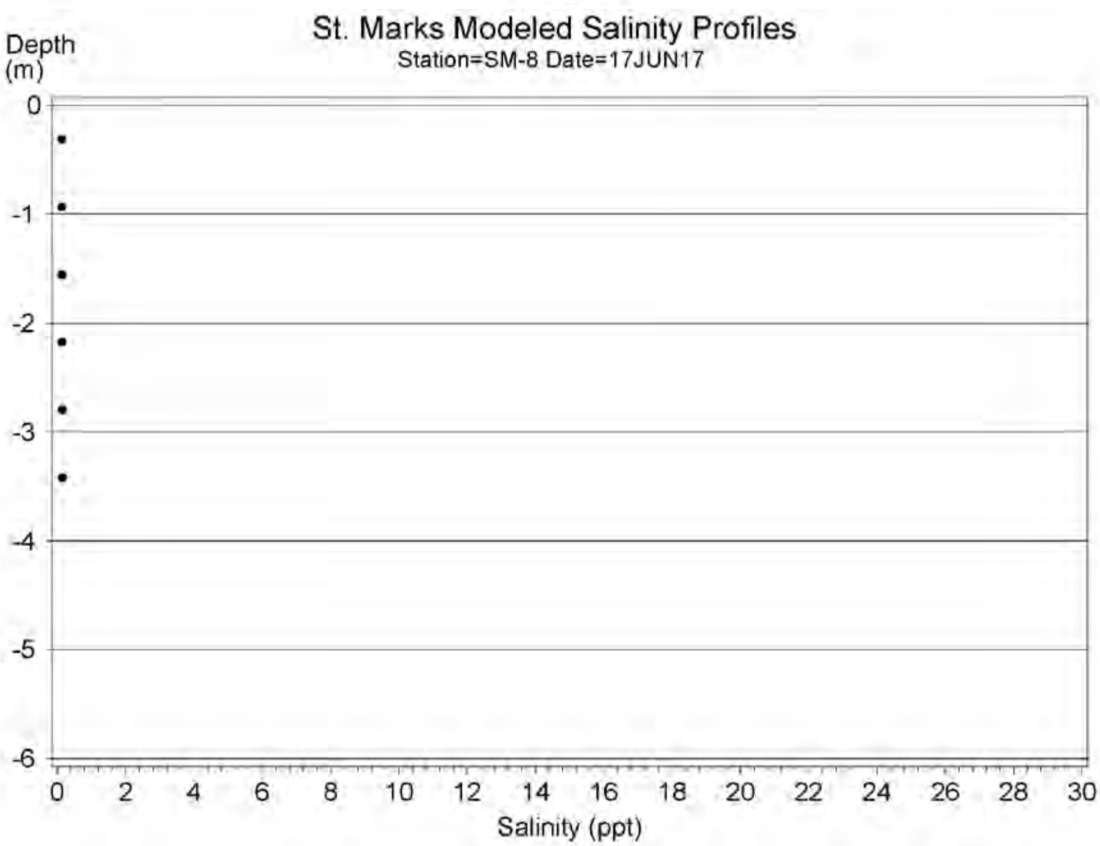
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-8 Date=17JUN17
Depth (m)
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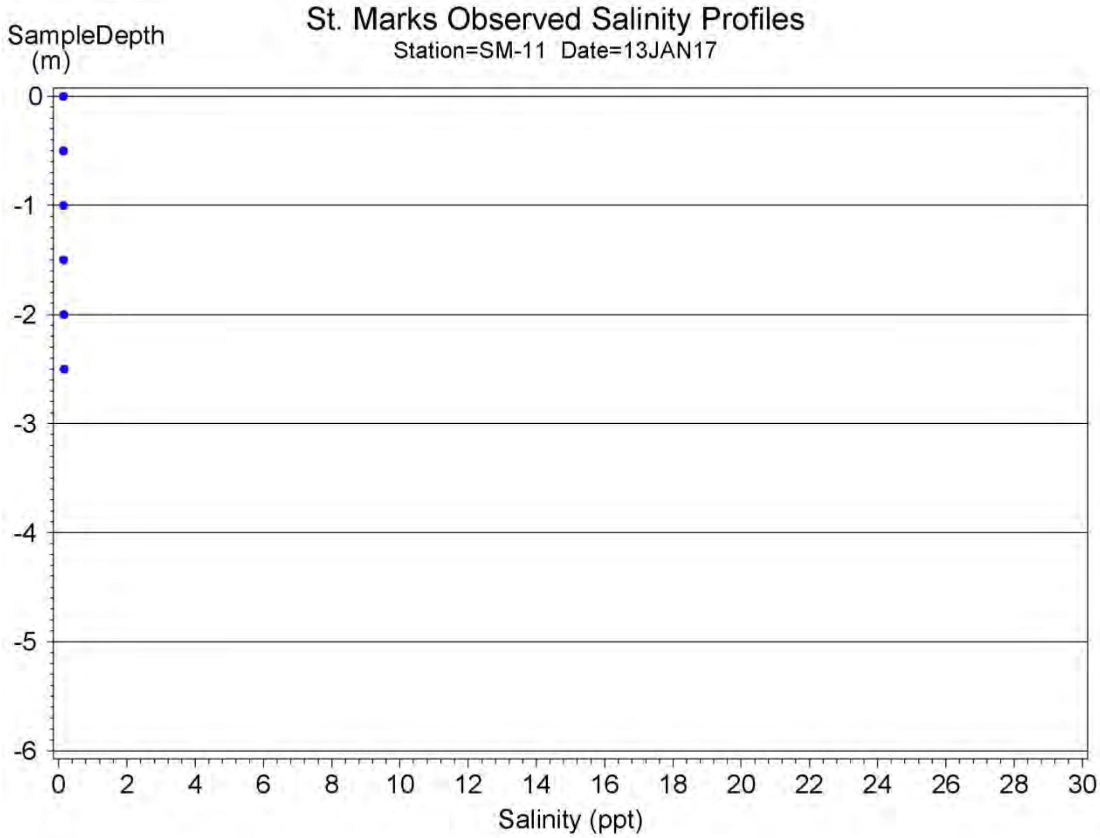
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-11 Date=13JAN17
SampleDepth (m)
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-2
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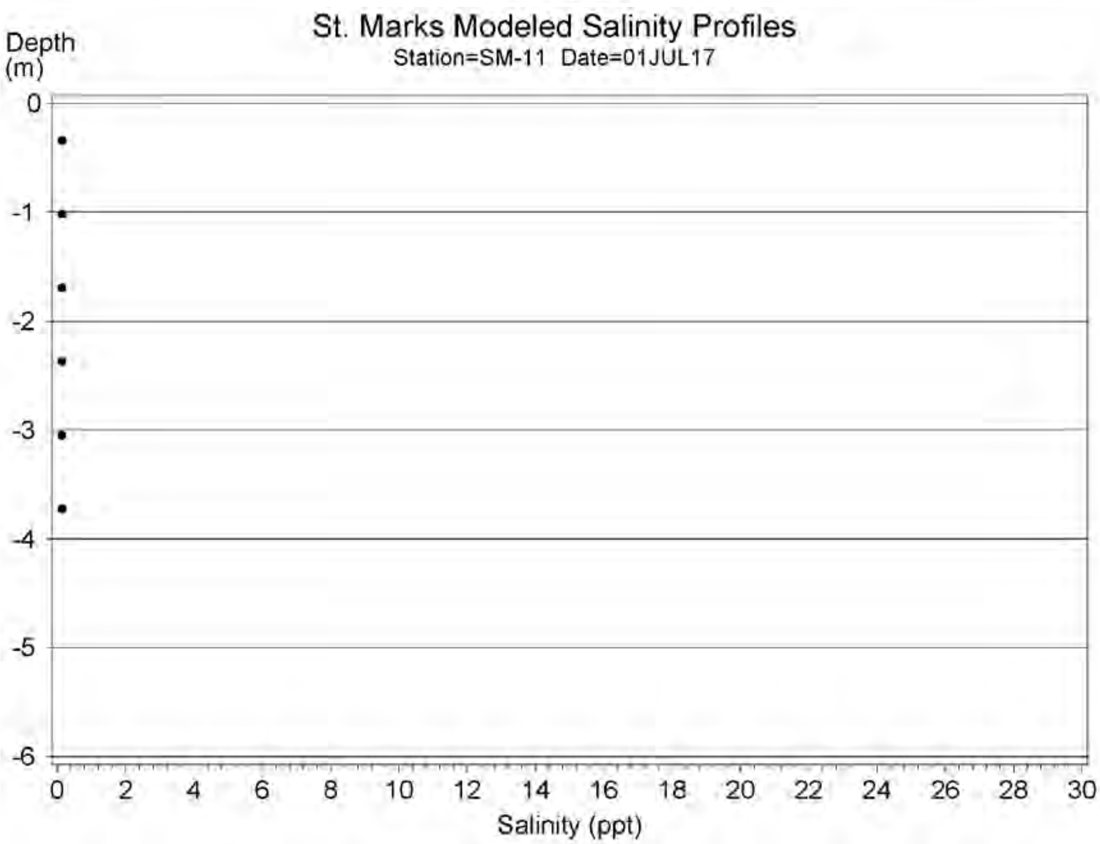
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-11 Date=01JUL17
Depth (m)
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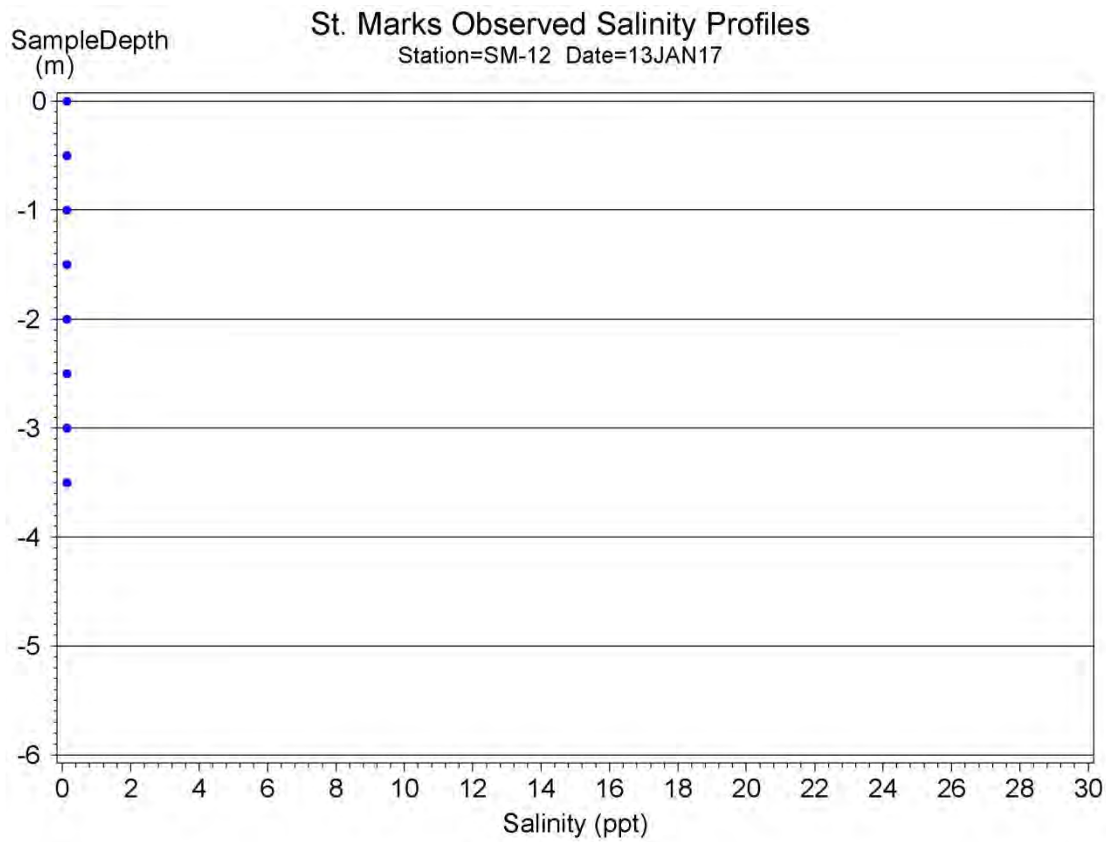
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-12 Date=13JAN17
SampleDepth
(m)
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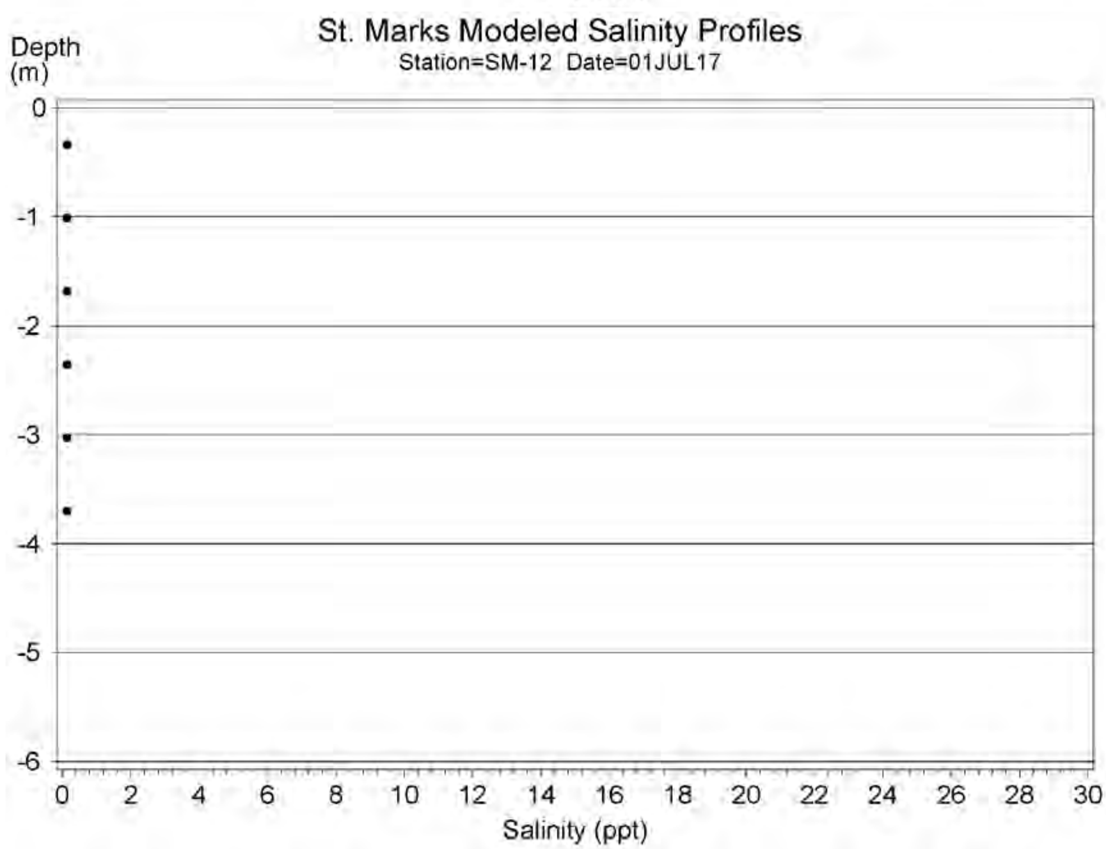
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-12 Date=01JUL17
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(m)
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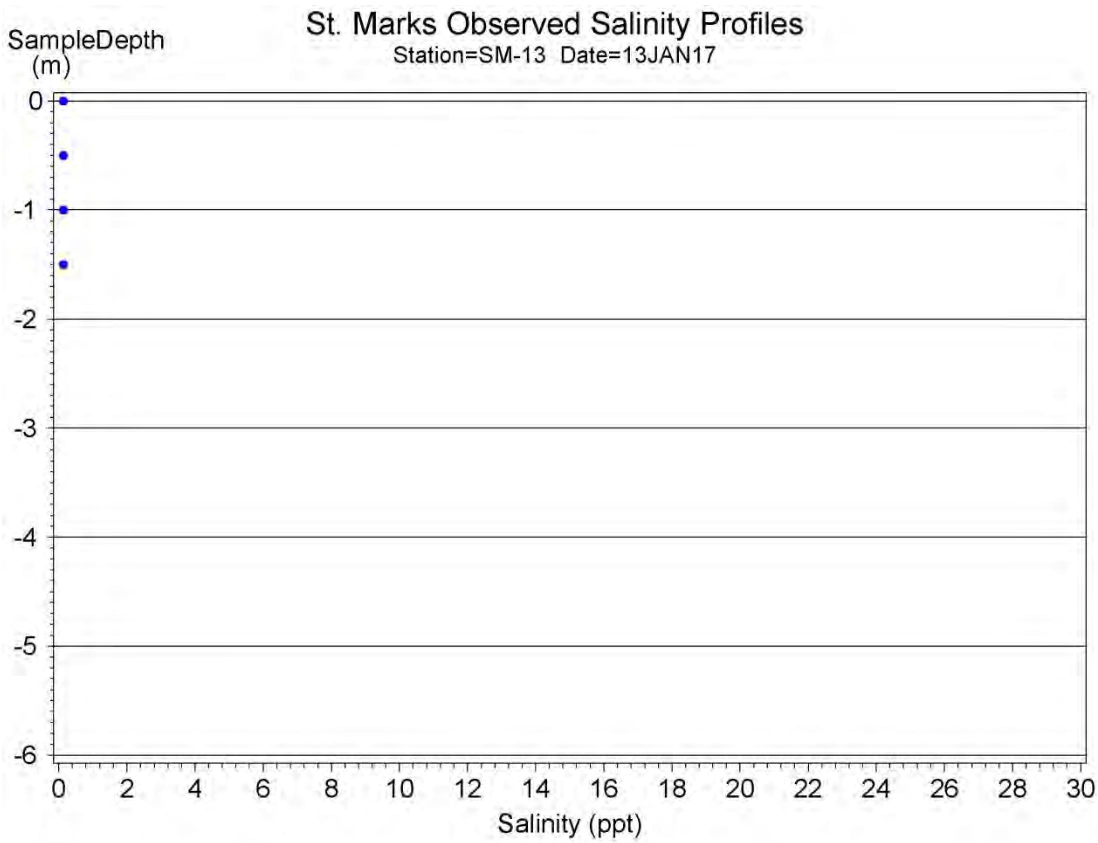
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-13 Date=13JAN17
SampleDepth (m)
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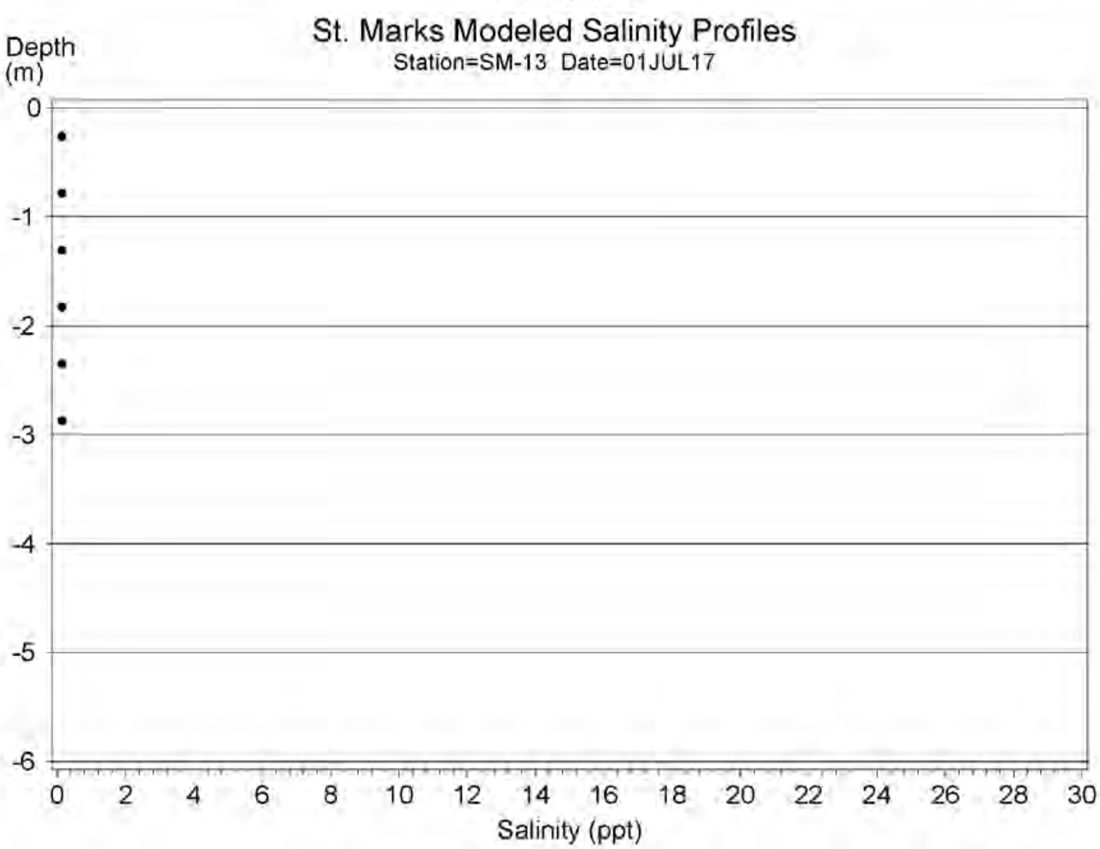
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-13 Date=01JUL17
Depth (m)
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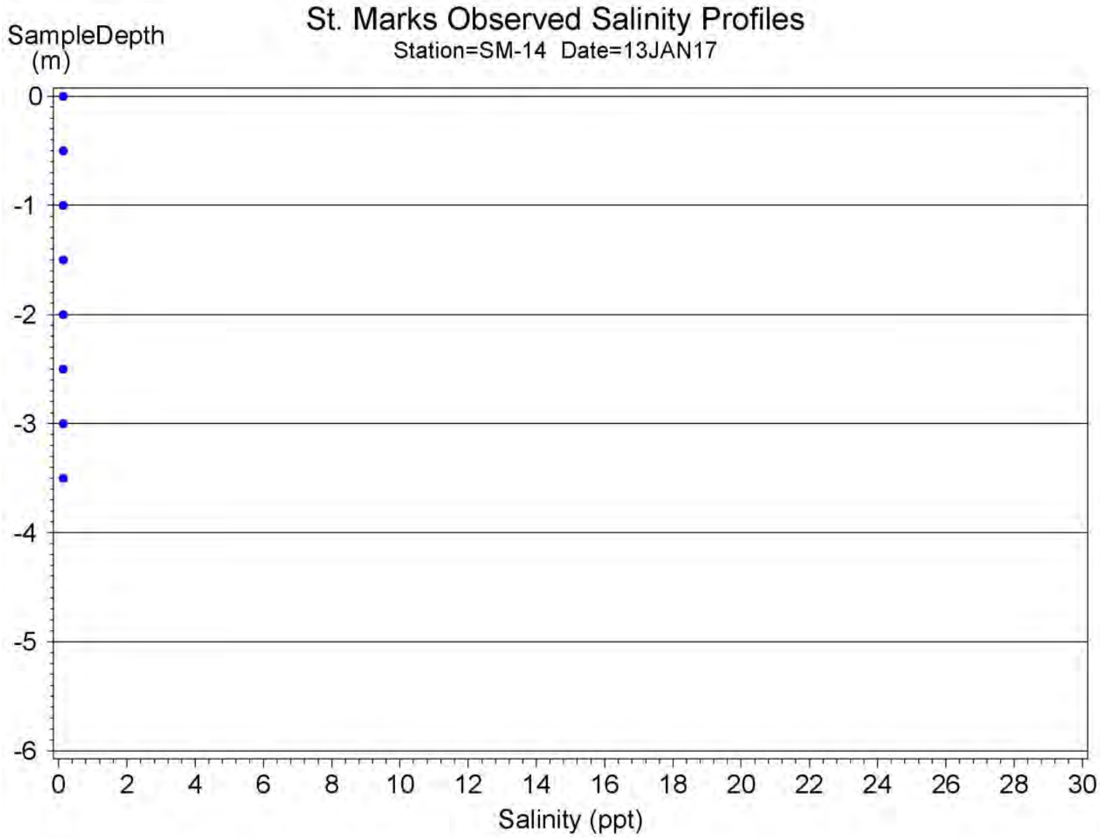
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-14 Date=13JAN17
SampleDepth (m)
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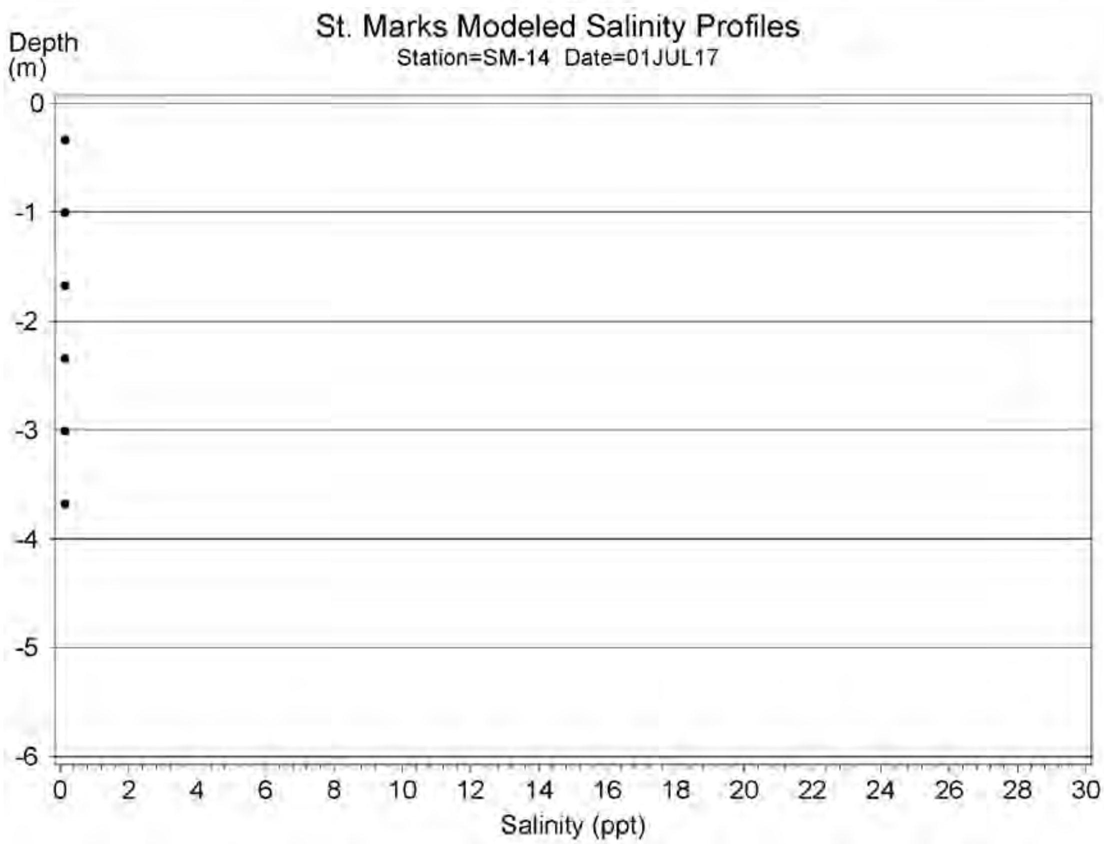
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-14 Date=01JUL17
Depth (m)
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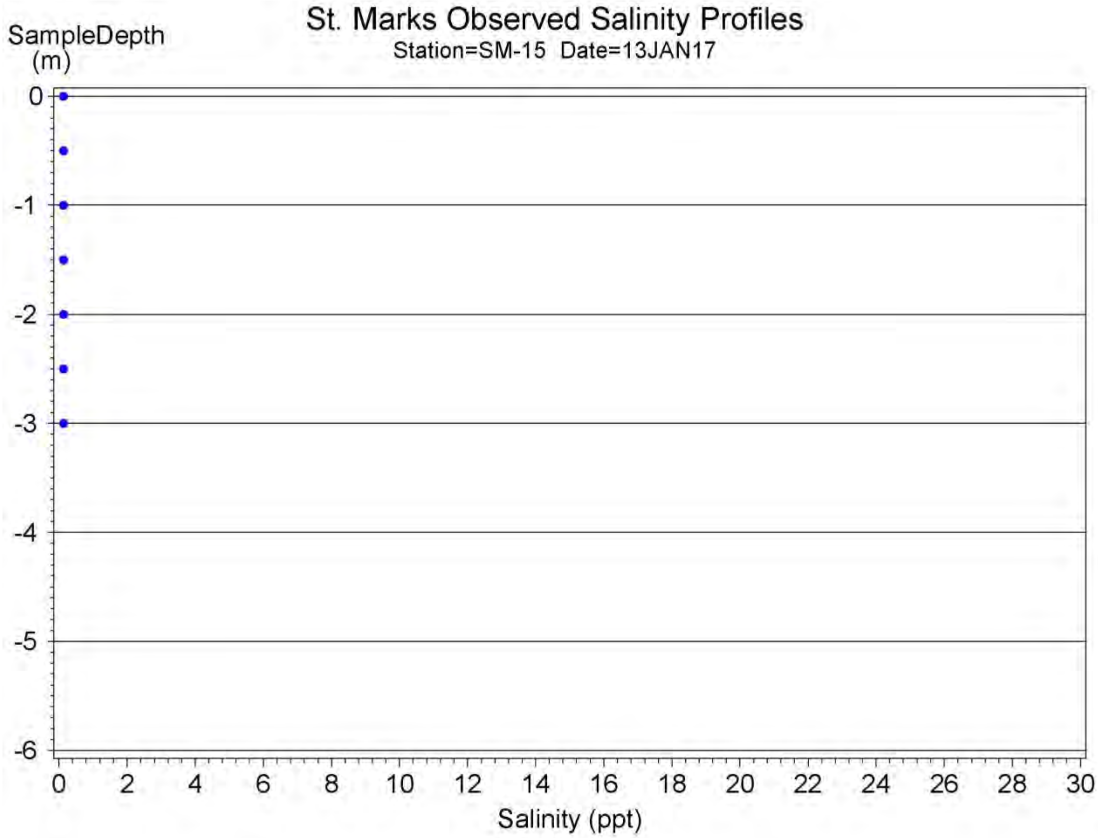
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-15 Date=13JAN17
SampleDepth (m)
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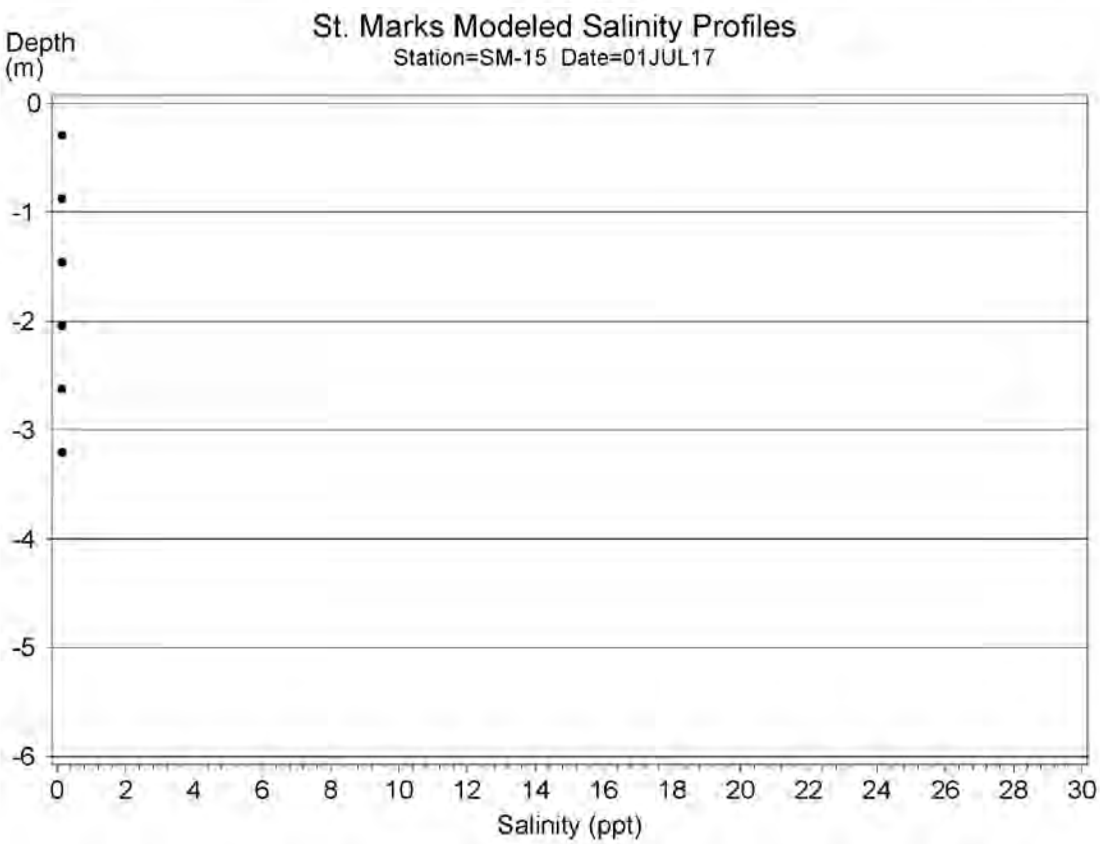
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-15 Date=01JUL17
Depth (m)
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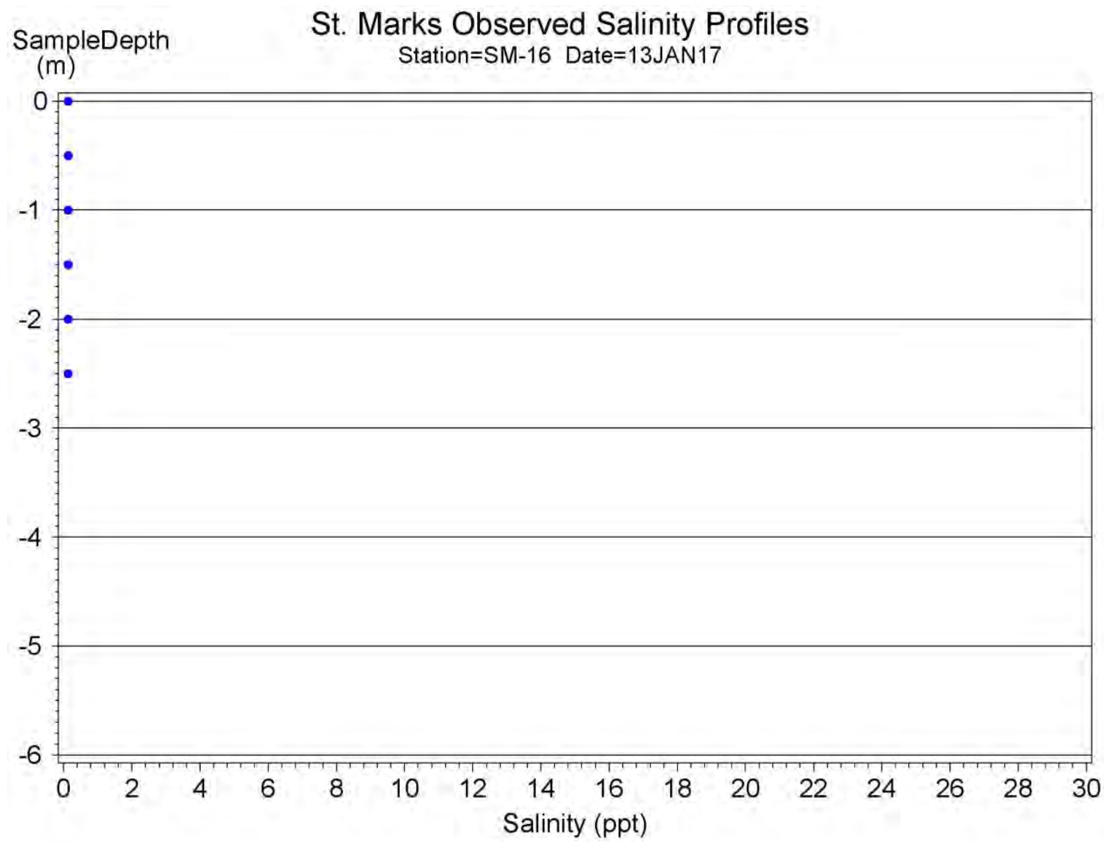
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-16 Date=13JAN17
SampleDepth
(m)
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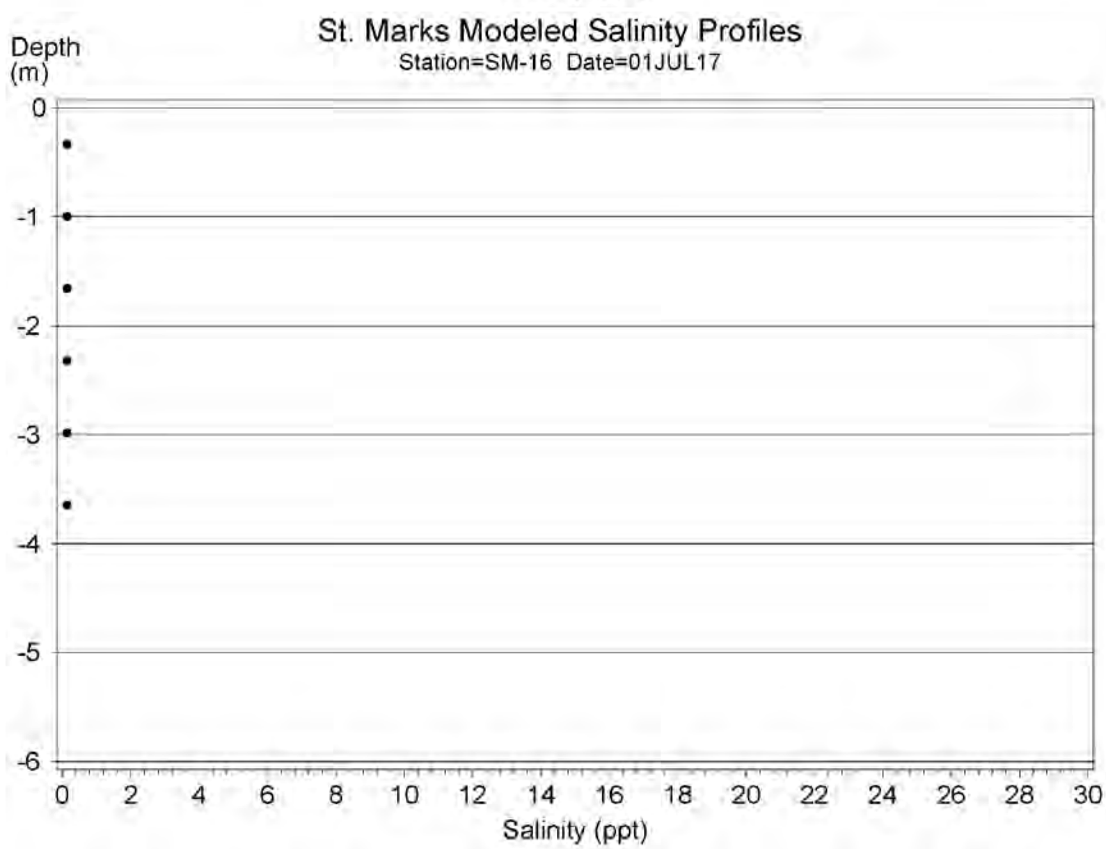
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-16 Date=01JUL17
Depth
(m)
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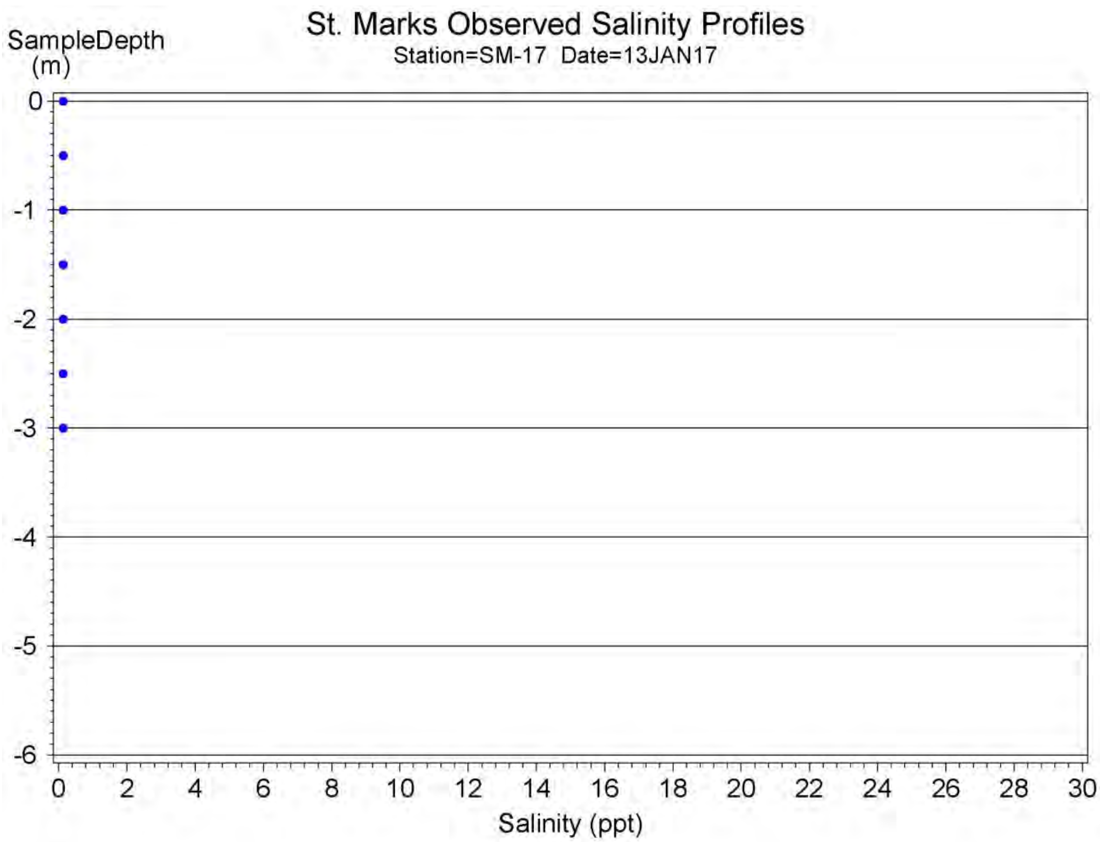
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-17 Date=13JAN17
SampleDepth (m)
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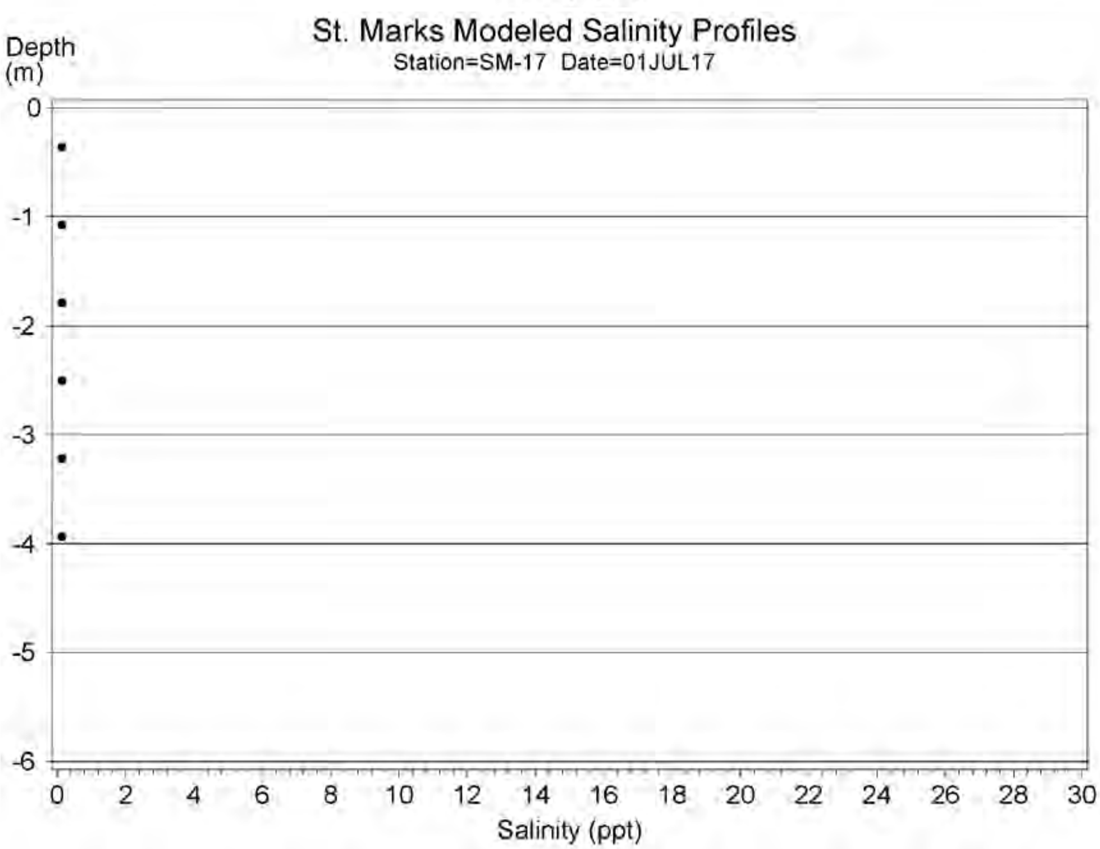
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-17 Date=01JUL17
Depth (m)
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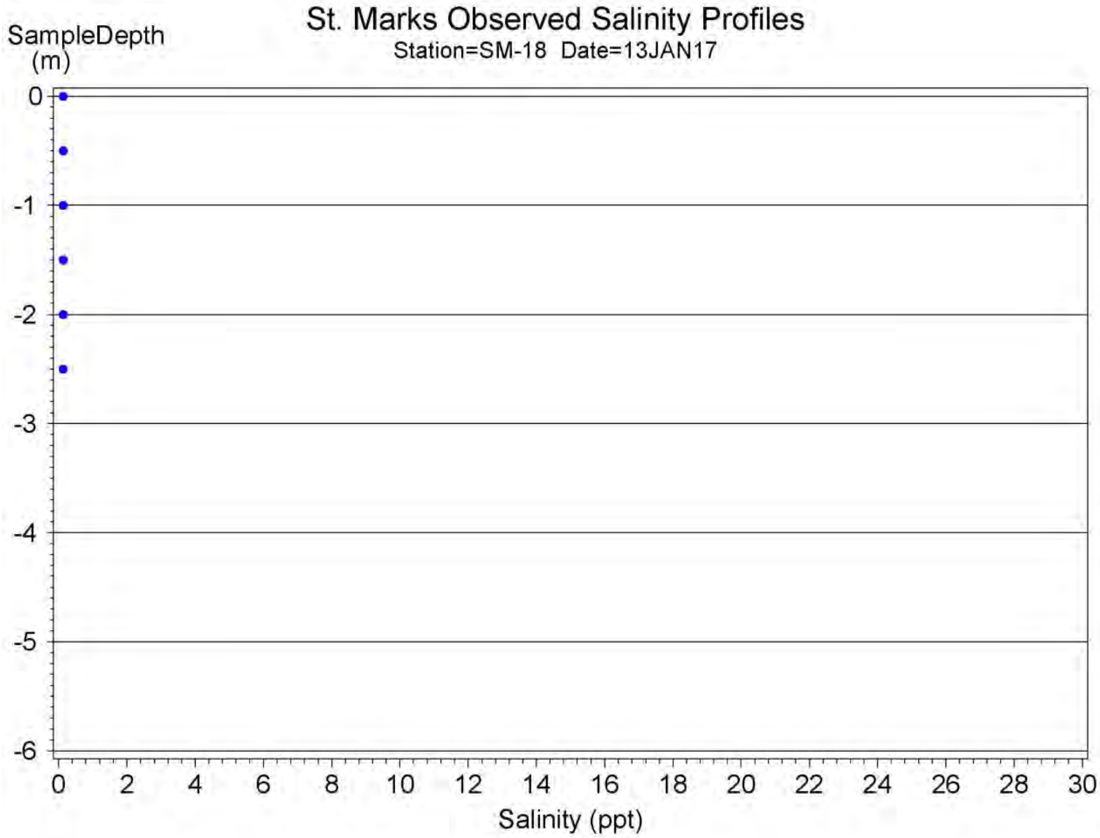
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-18 Date=13JAN17
SampleDepth (m)
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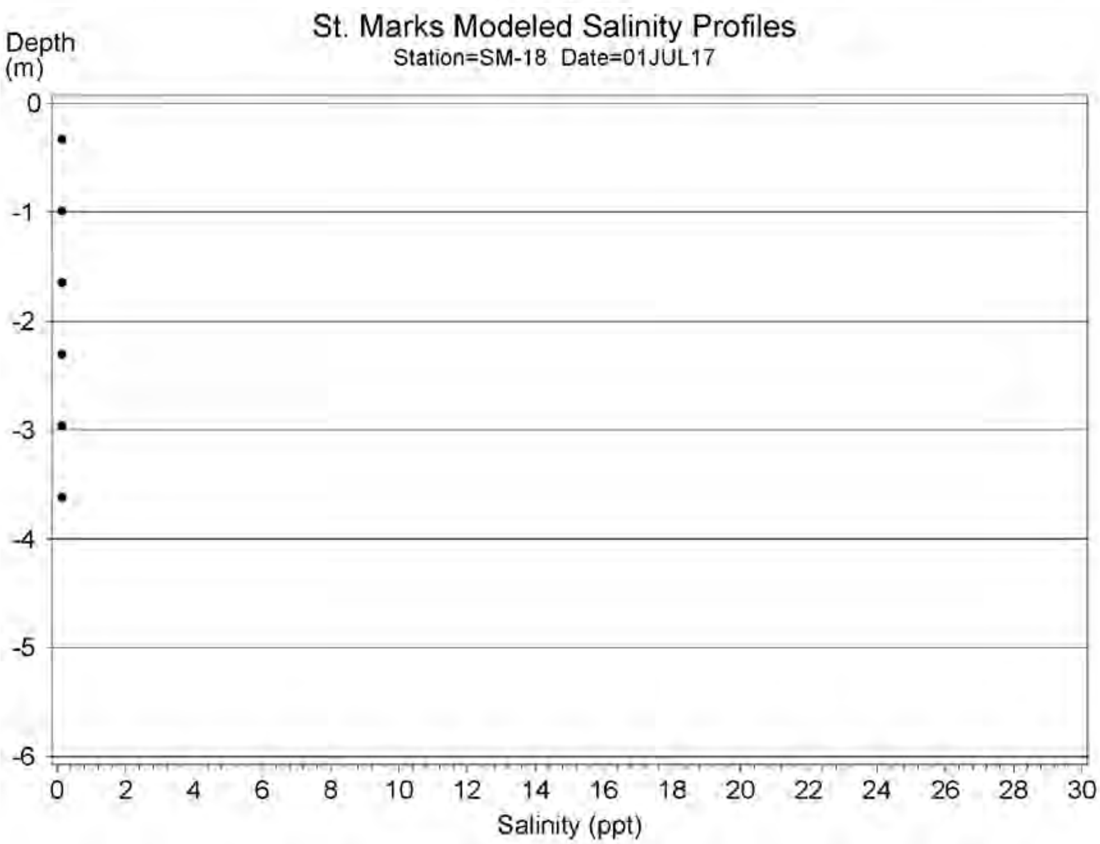
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-18 Date=01JUL17
Depth (m)
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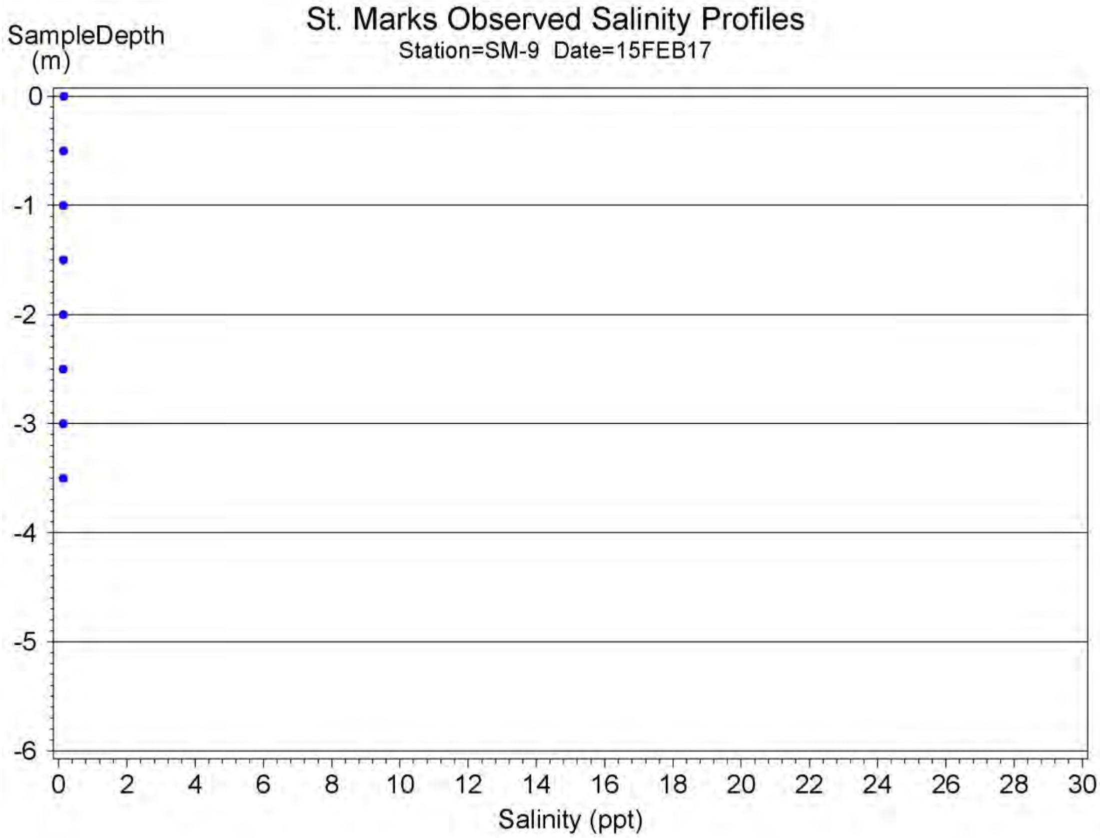
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-9 Date=15FEB17
SampleDepth
(m)
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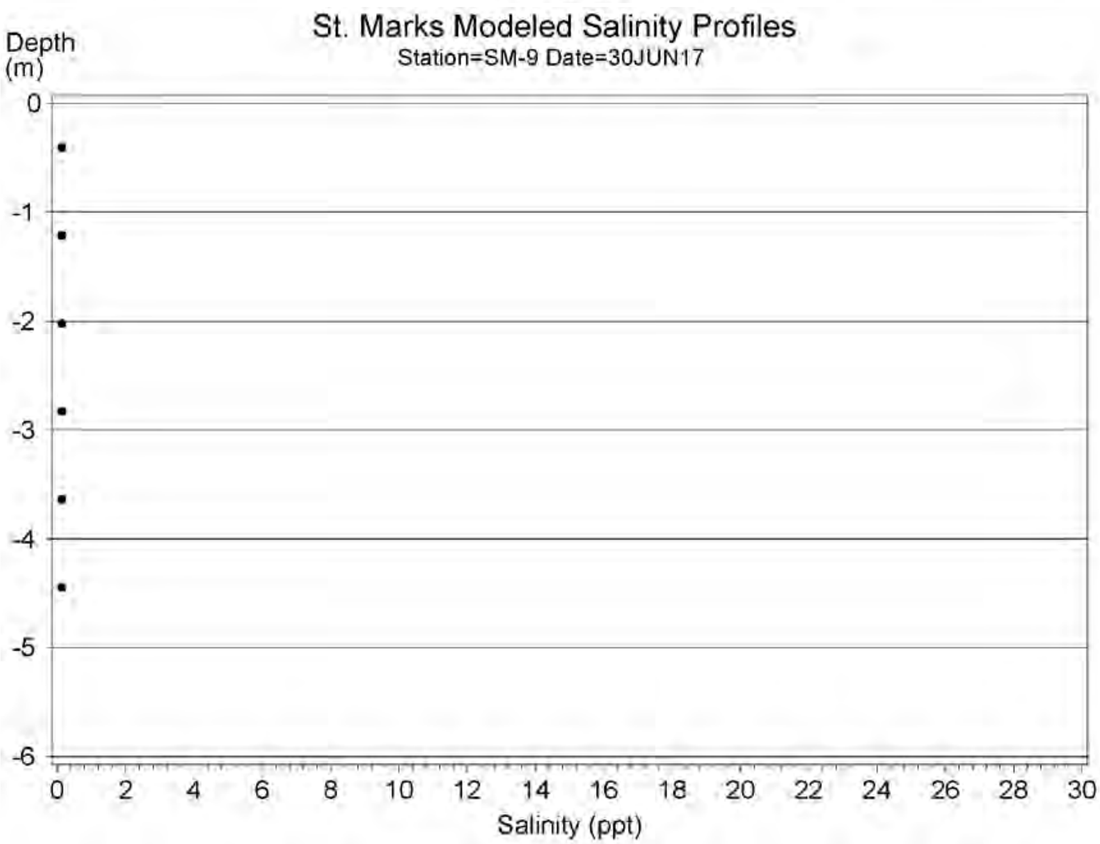
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-9 Date=30JUN17
Depth
(m)
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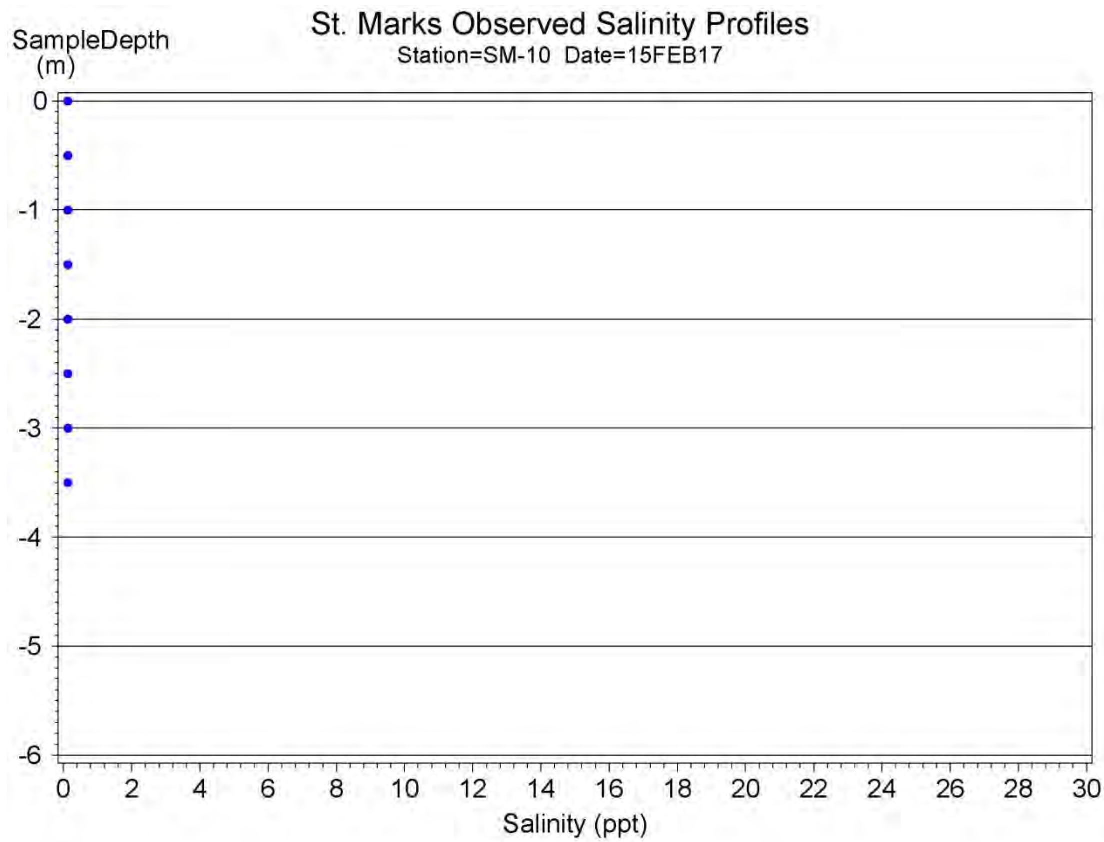
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-10 Date=15FEB17
SampleDepth (m)
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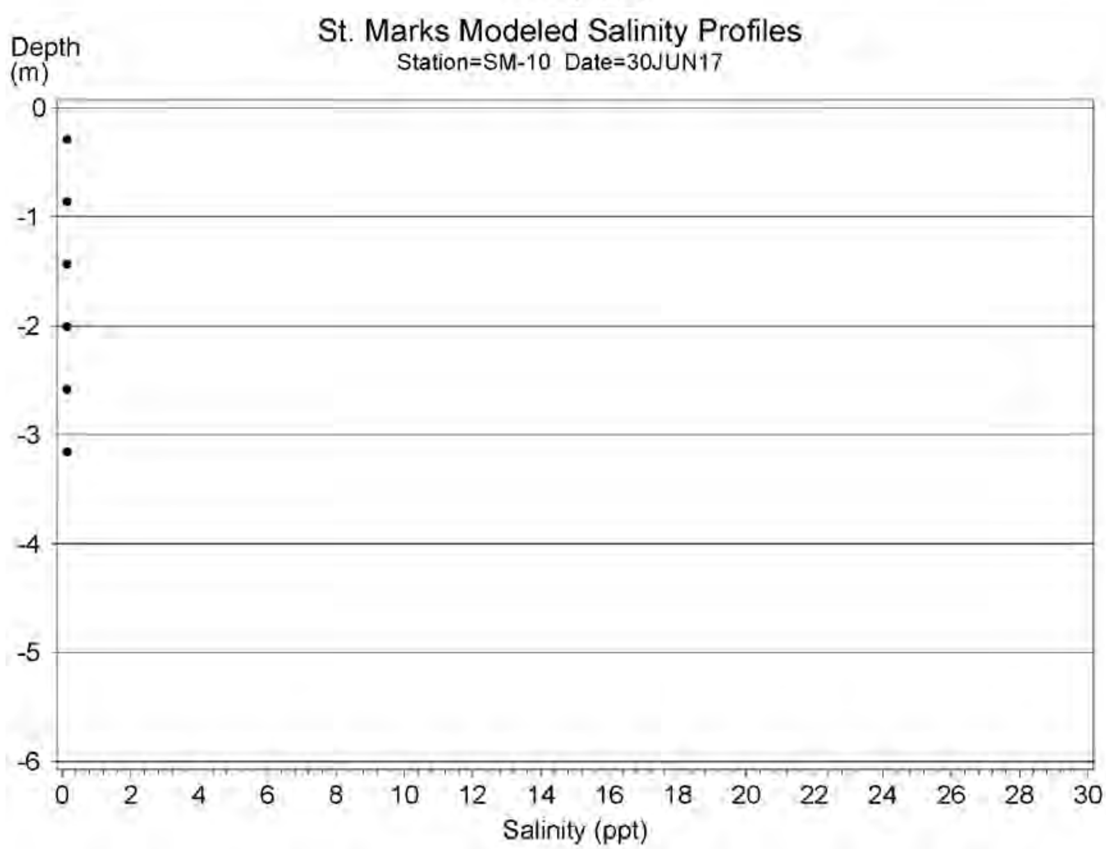
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-10 Date=30JUN17
Depth (m)
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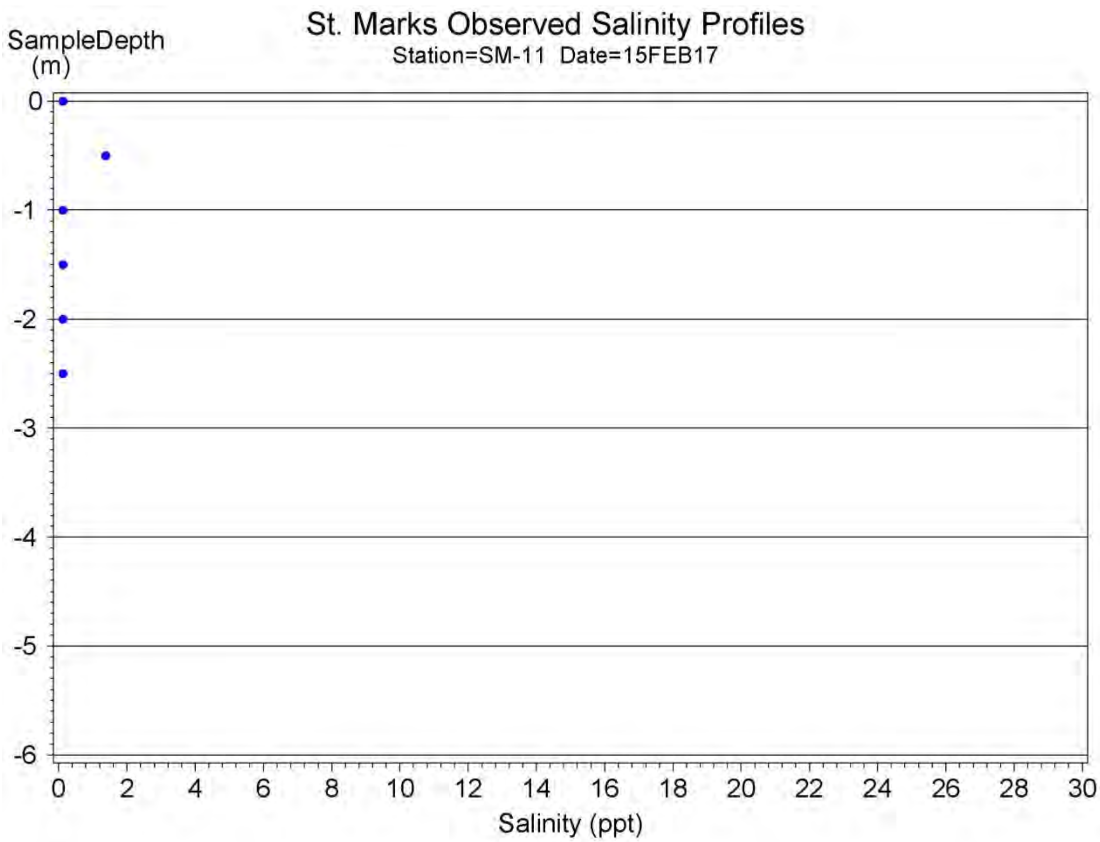
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-11 Date=15FEB17
SampleDepth (m)
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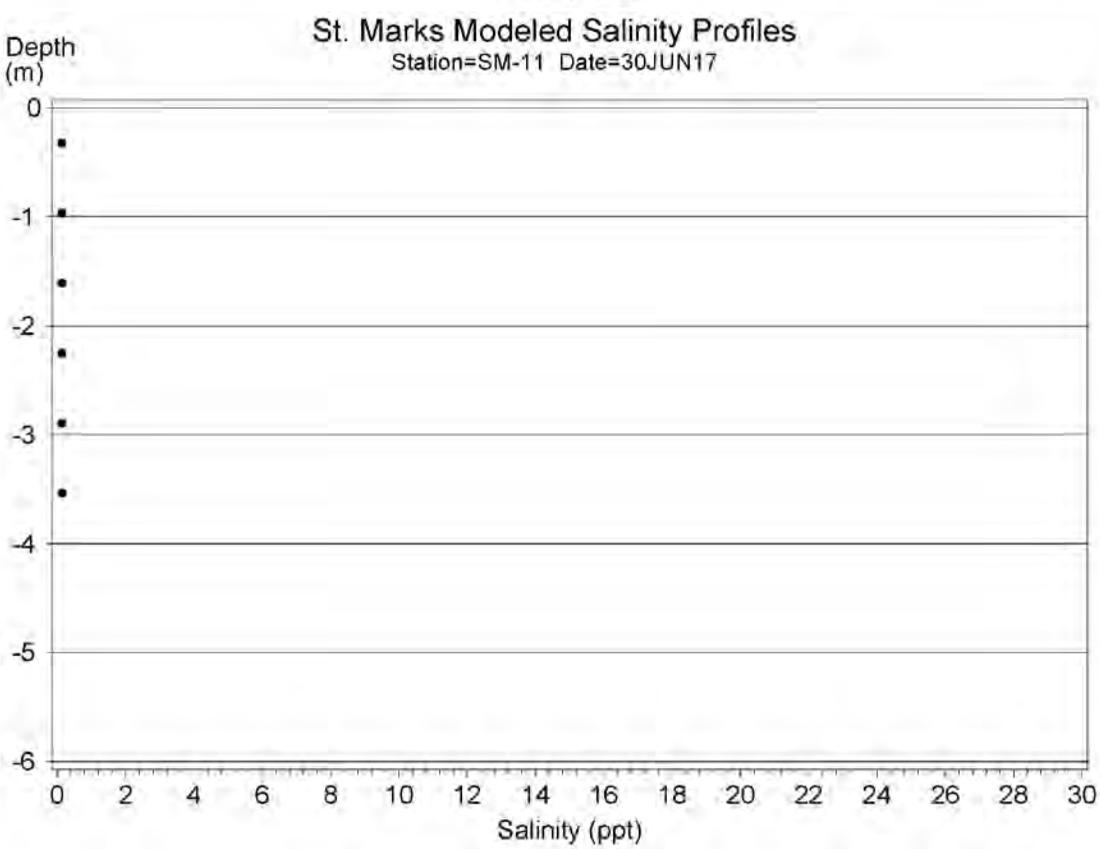
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-11 Date=30JUN17
Depth (m)
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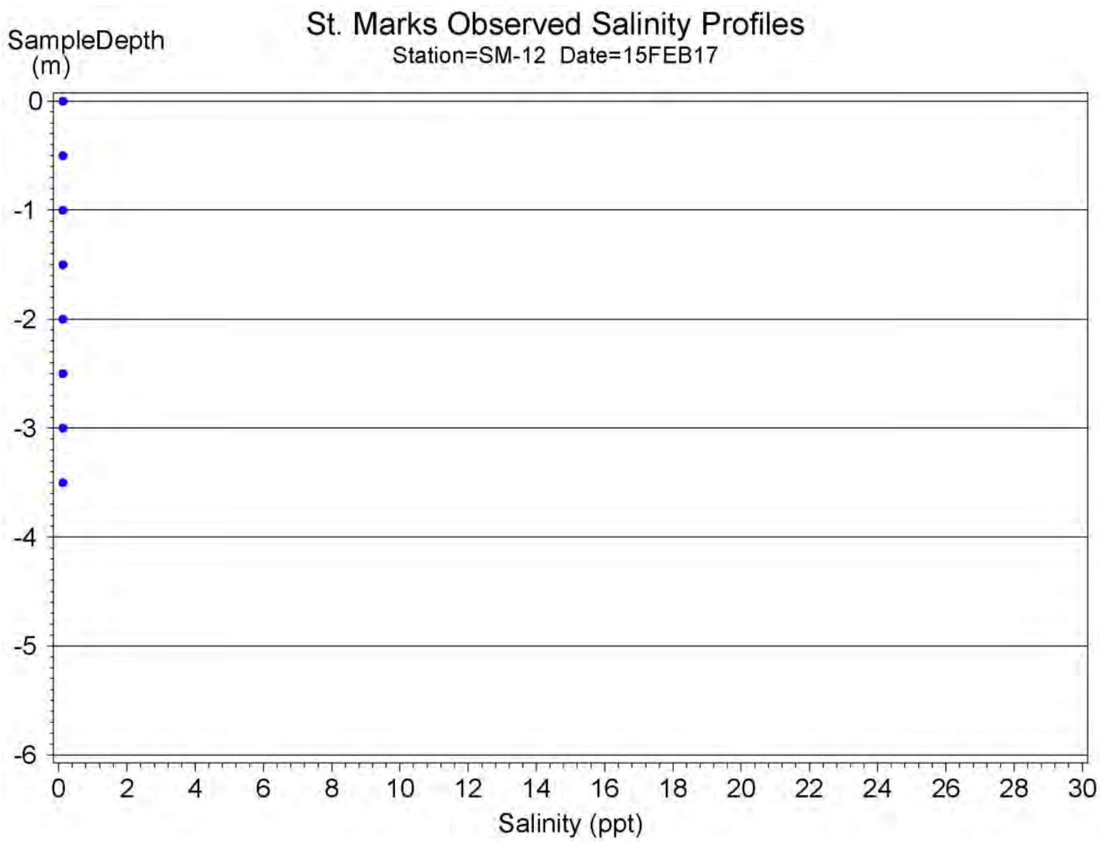
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-12 Date=15FEB17
SampleDepth (m)
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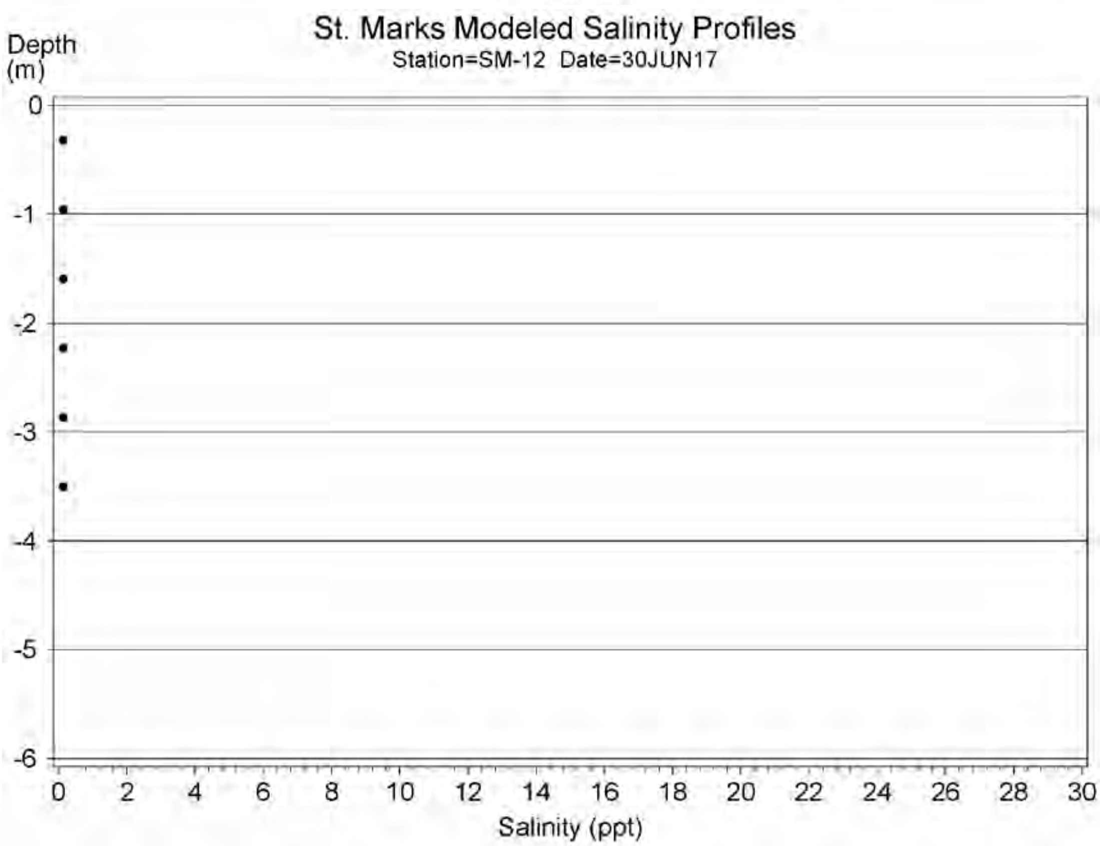
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-12 Date=30JUN17
Depth (m)
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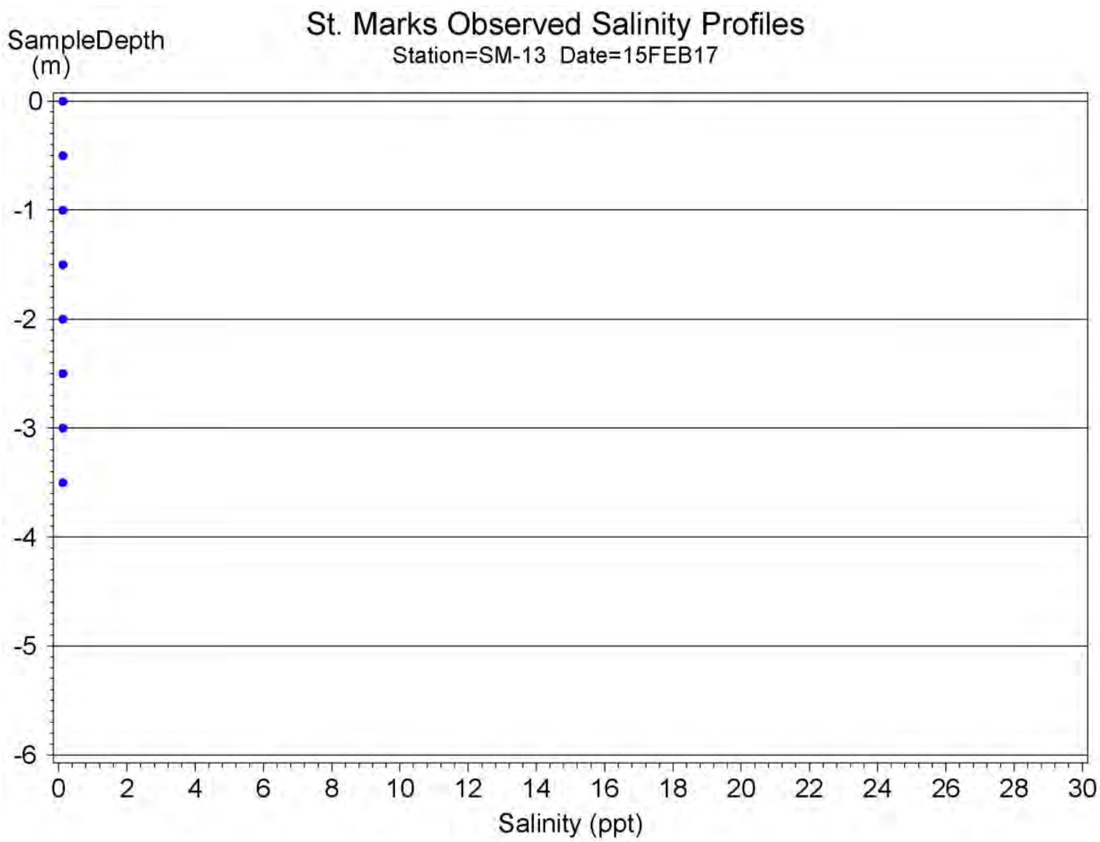
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-13 Date=15FEB17
SampleDepth (m)
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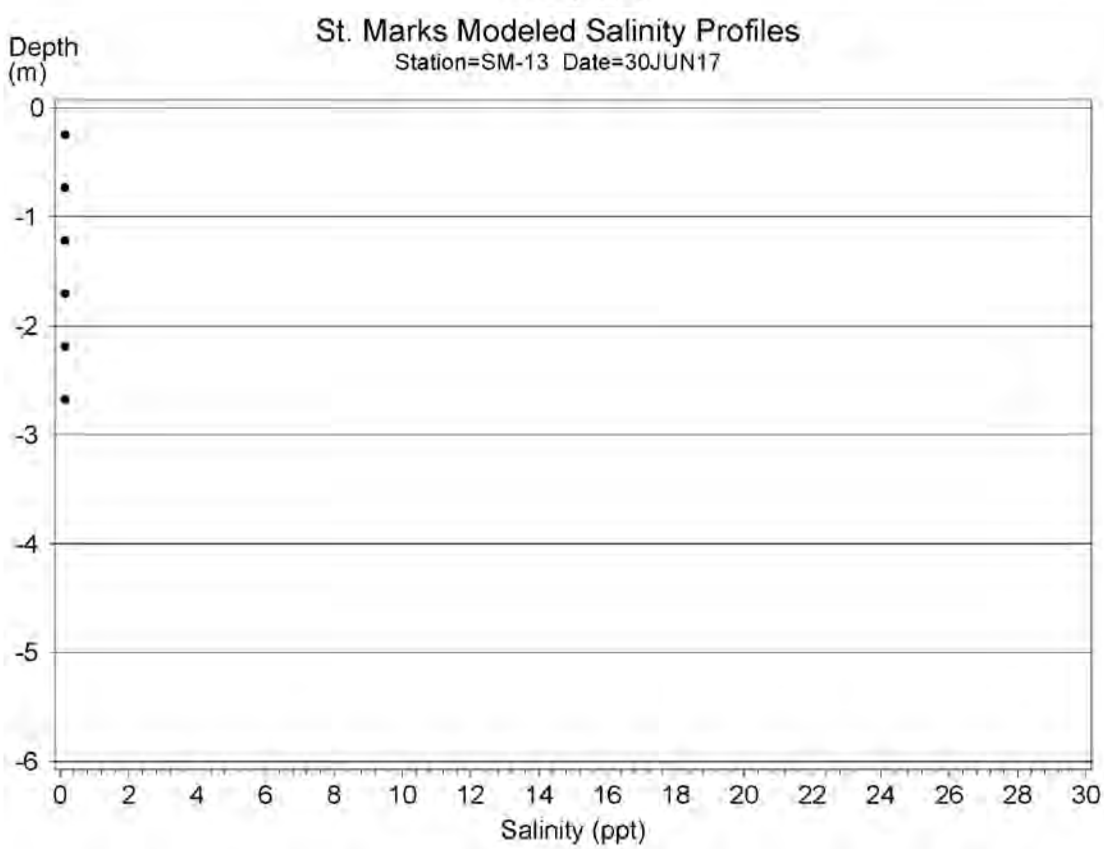
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-13 Date=30JUN17
Depth (m)
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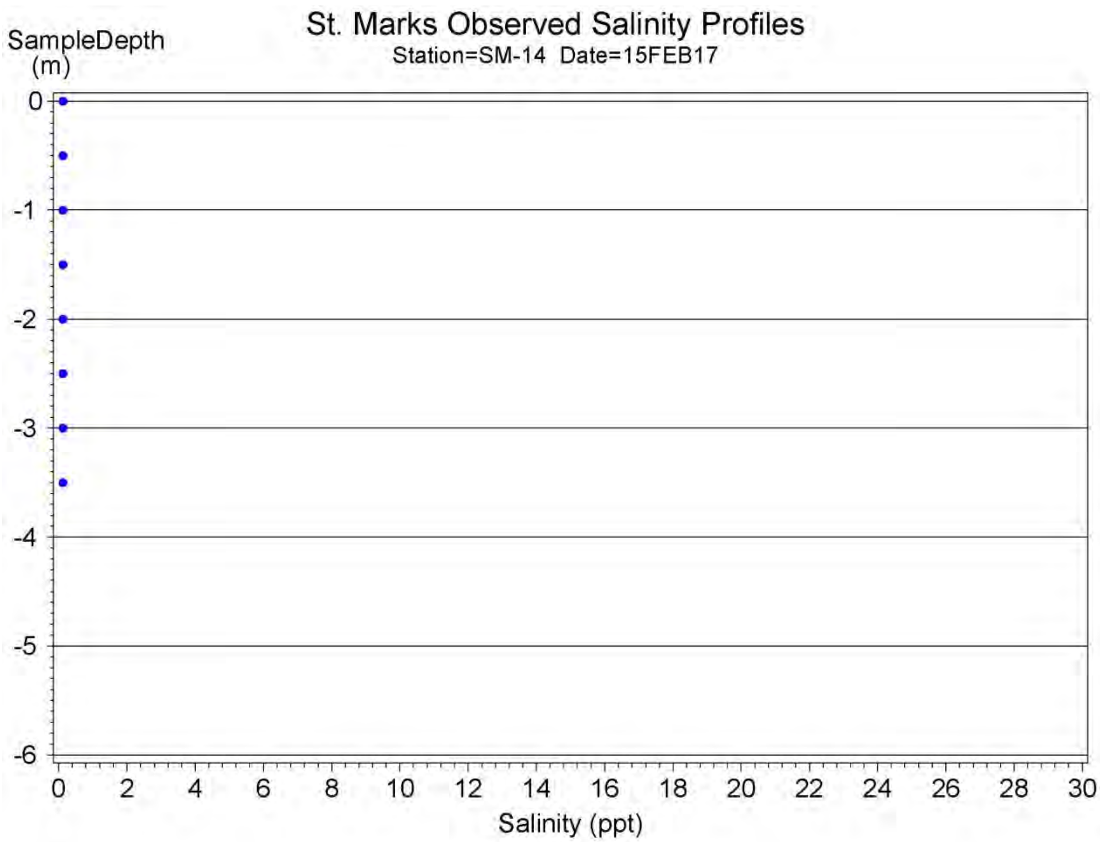
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-14 Date=15FEB17
SampleDepth (m)
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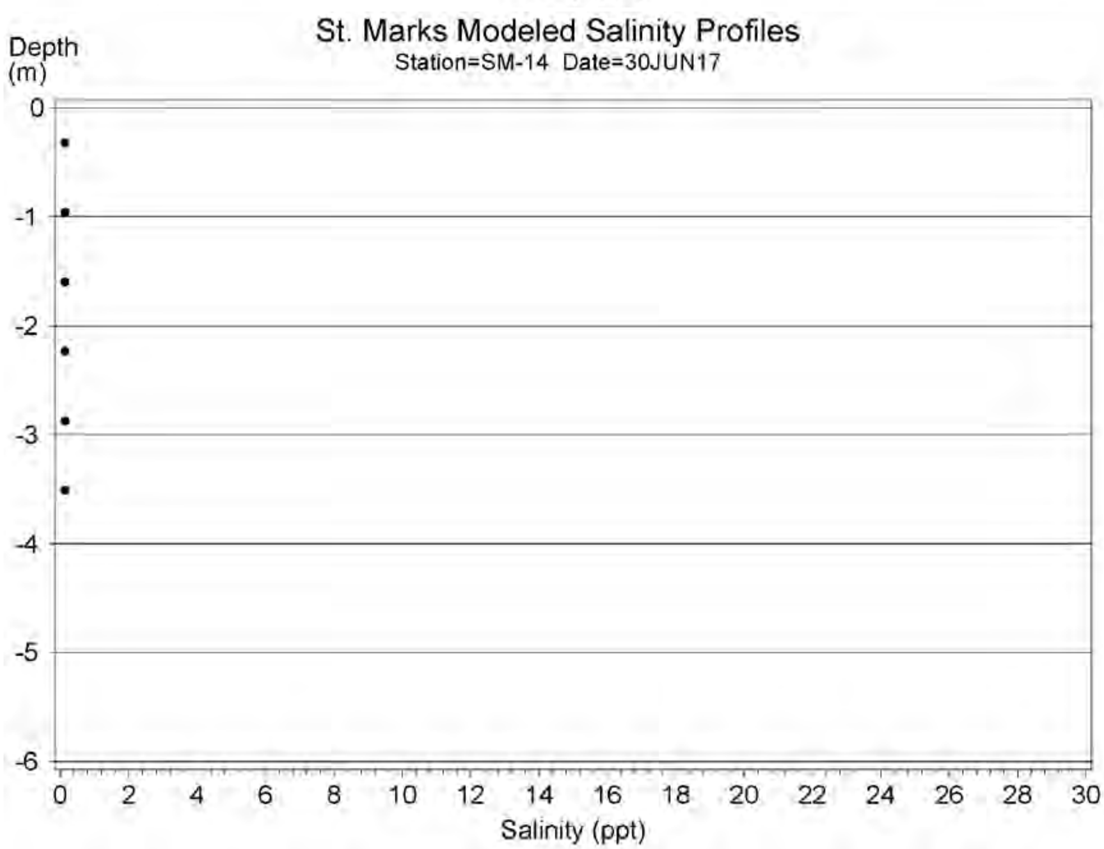
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-14 Date=30JUN17
Depth (m)
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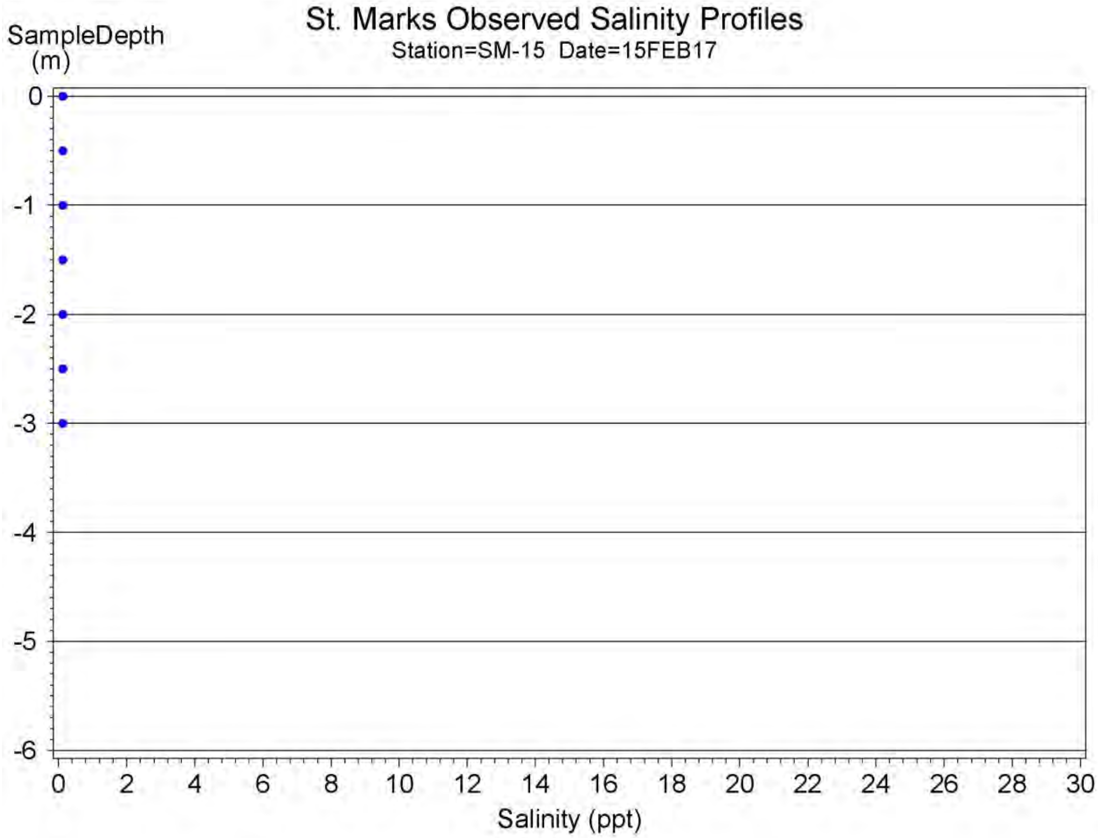
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-15 Date=15FEB17
SampleDepth (m)
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-4
-5
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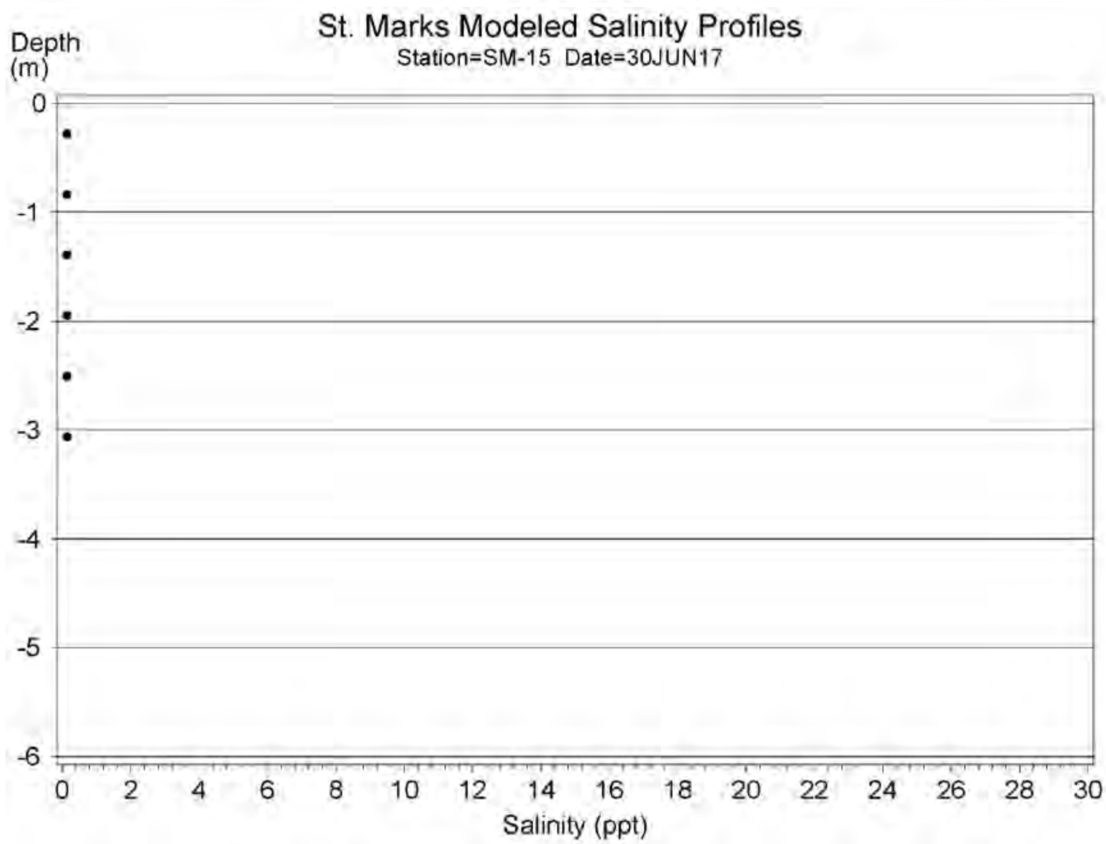
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-15 Date=30JUN17
Depth (m)
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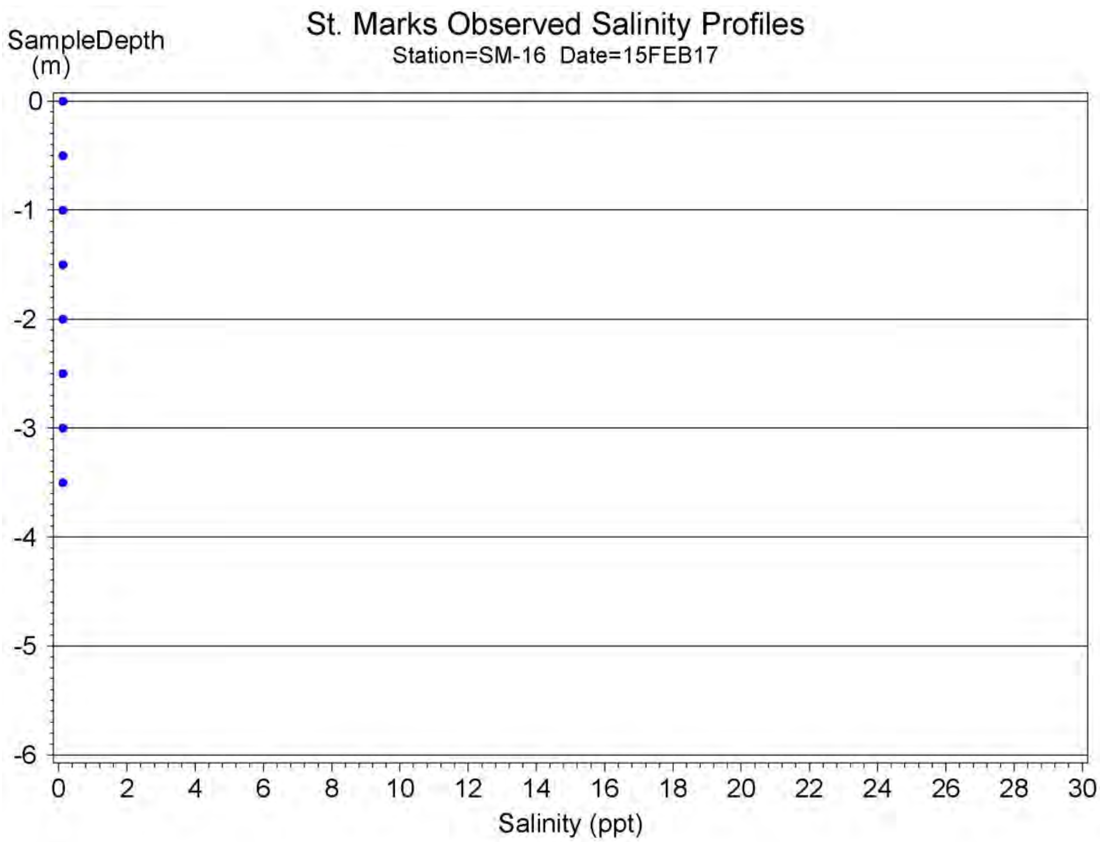
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-16 Date=15FEB17
SampleDepth (m)
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-5
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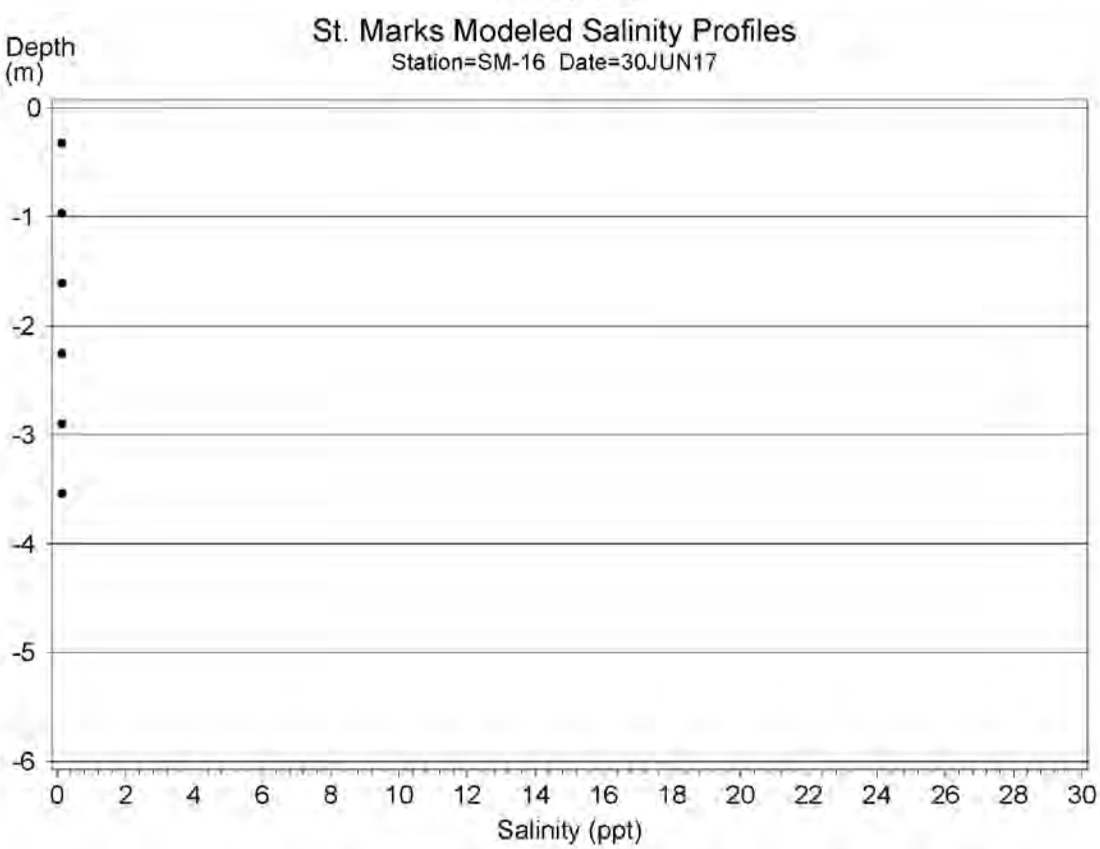
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-16 Date=30JUN17
Depth (m)
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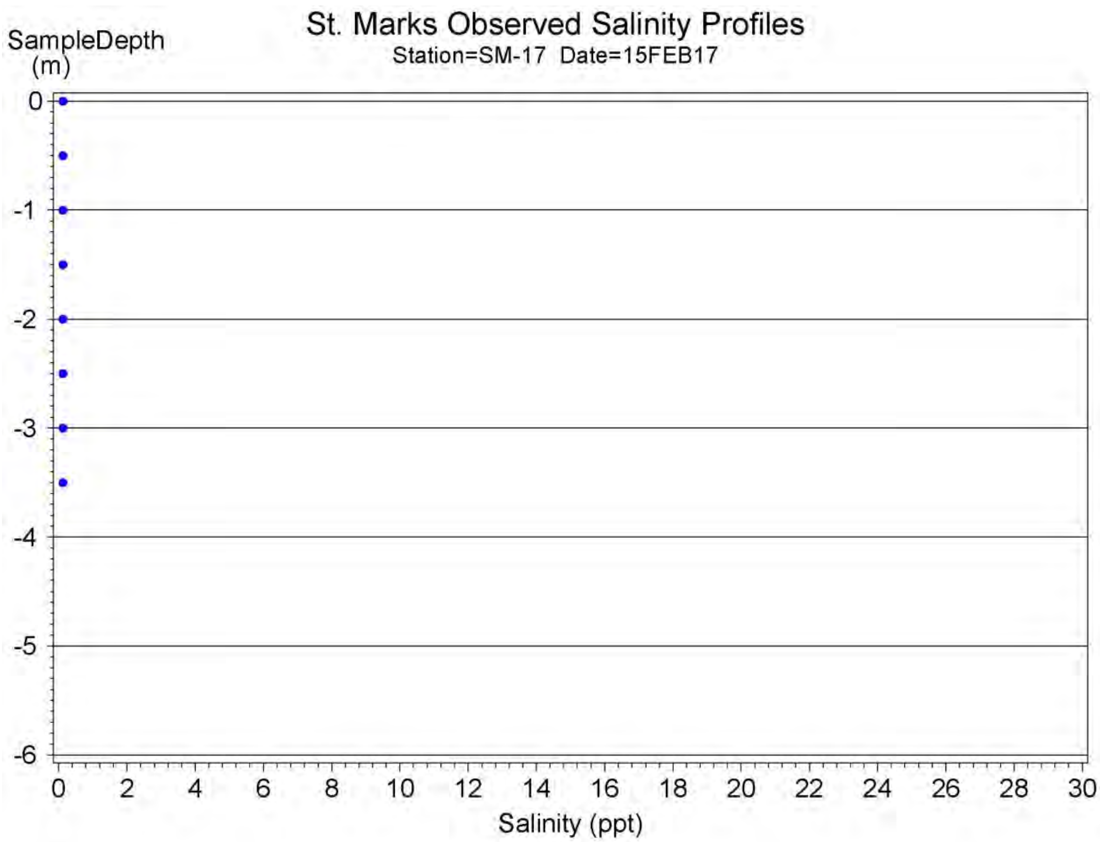
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-17 Date=15FEB17
SampleDepth (m)
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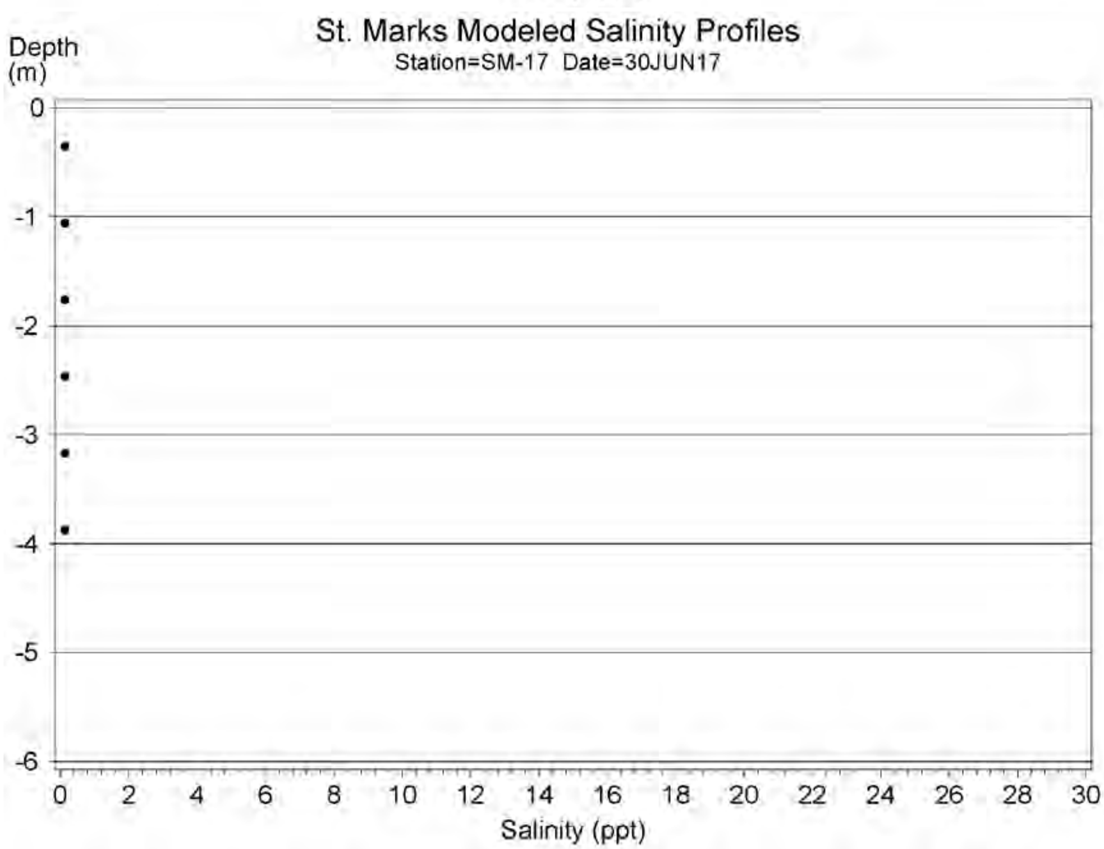
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-17 Date=30JUN17
Depth (m)
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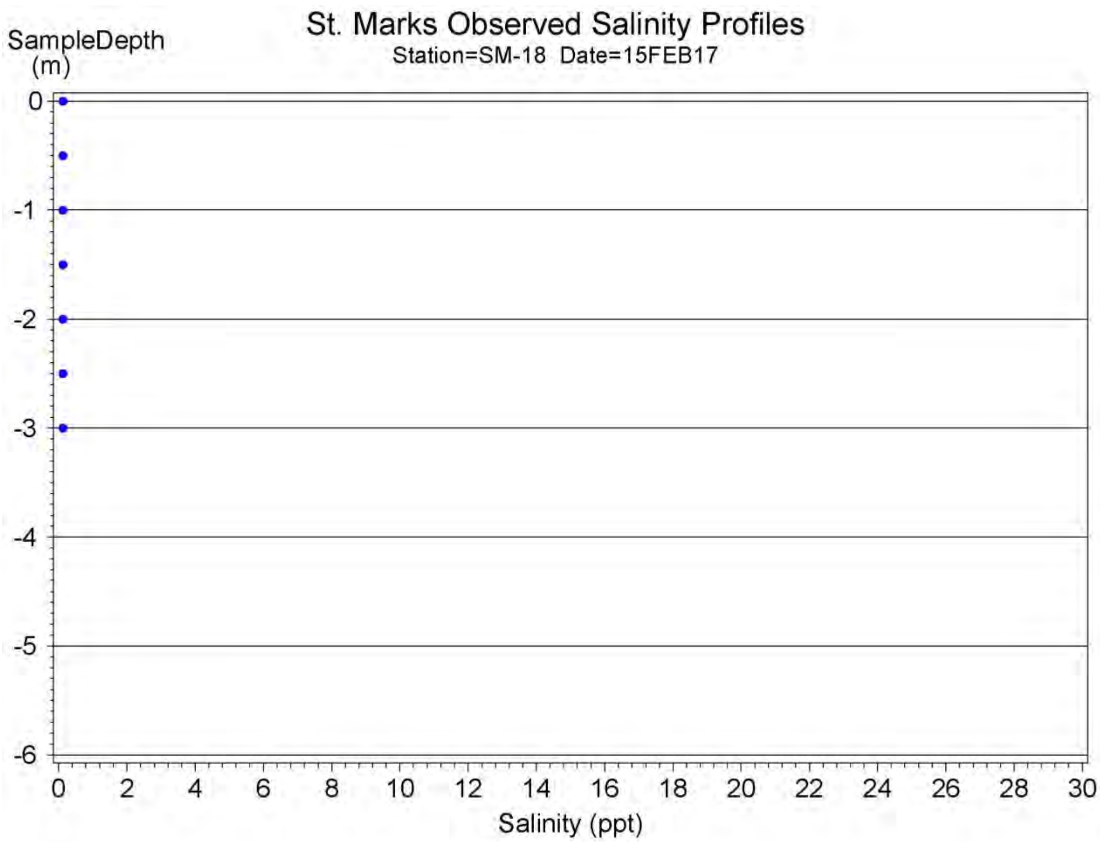
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-18 Date=15FEB17
SampleDepth (m)
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-4
-5
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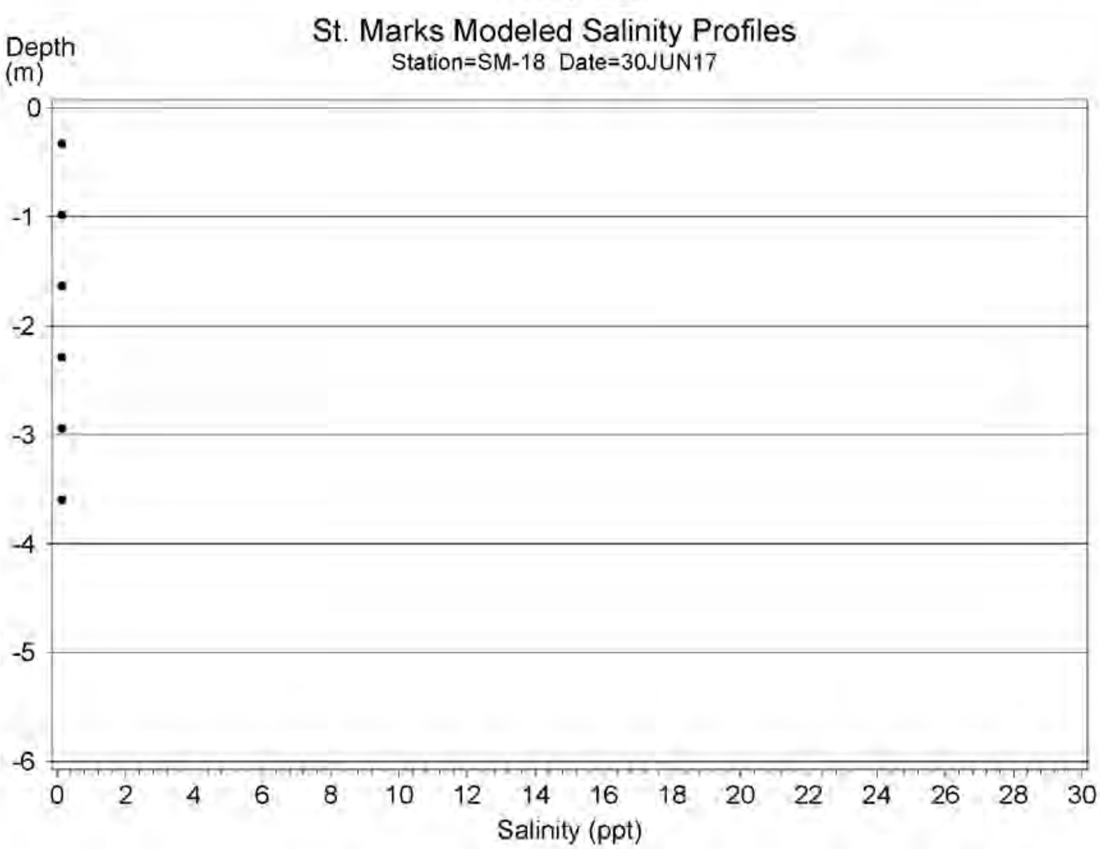
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-18 Date=30JUN17
Depth (m)
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-4
-5
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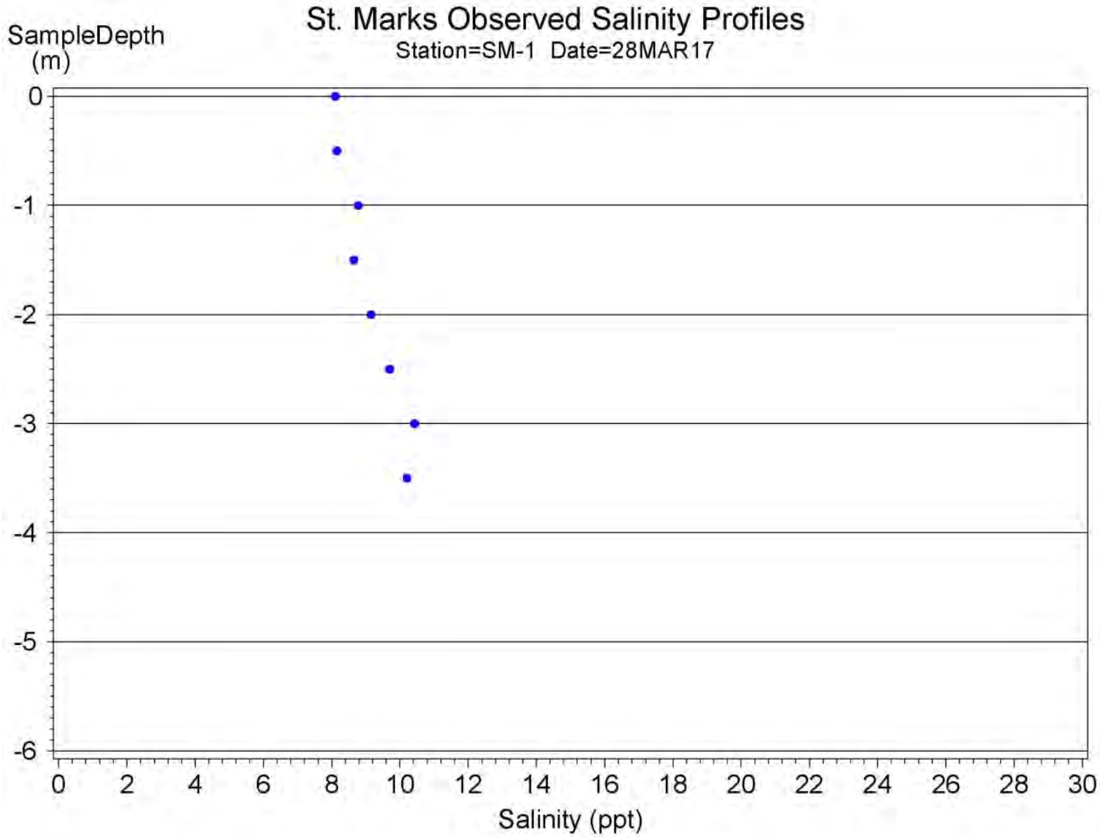
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-1 Date=28MAR17
SampleDepth (m)
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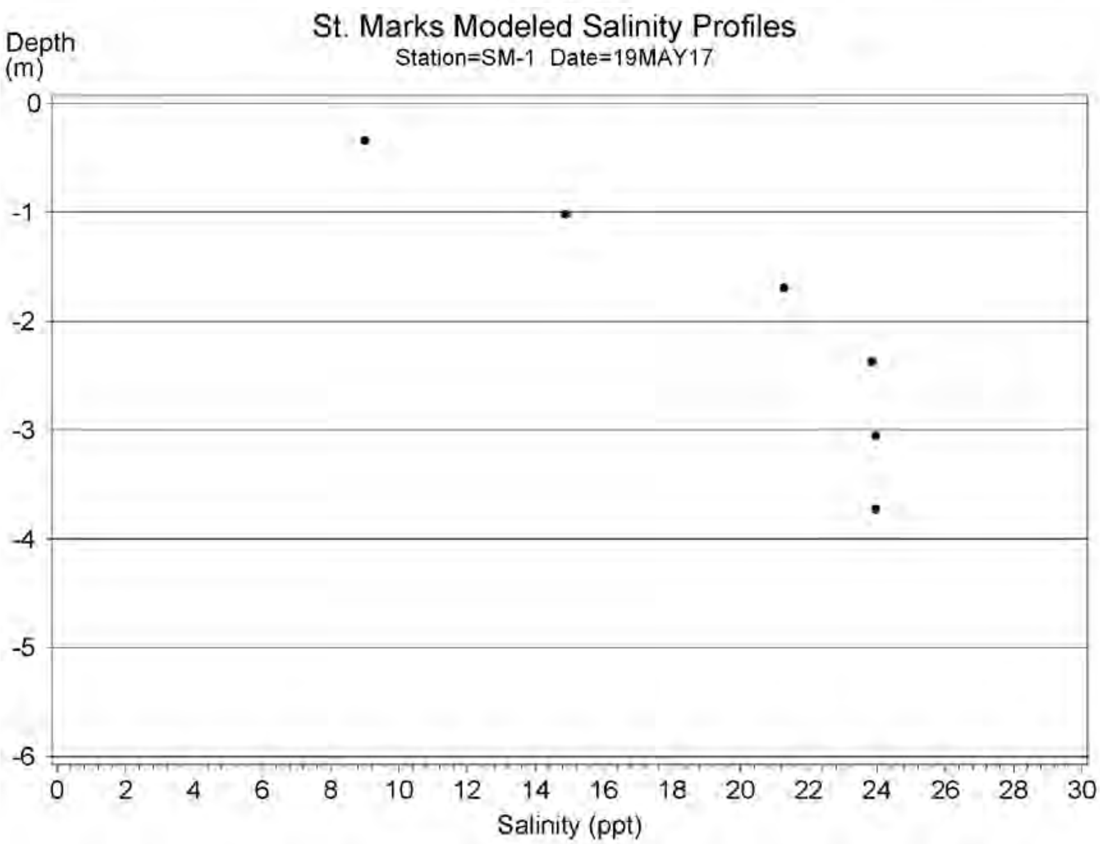
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-1 Date=19MAY17
Depth (m)
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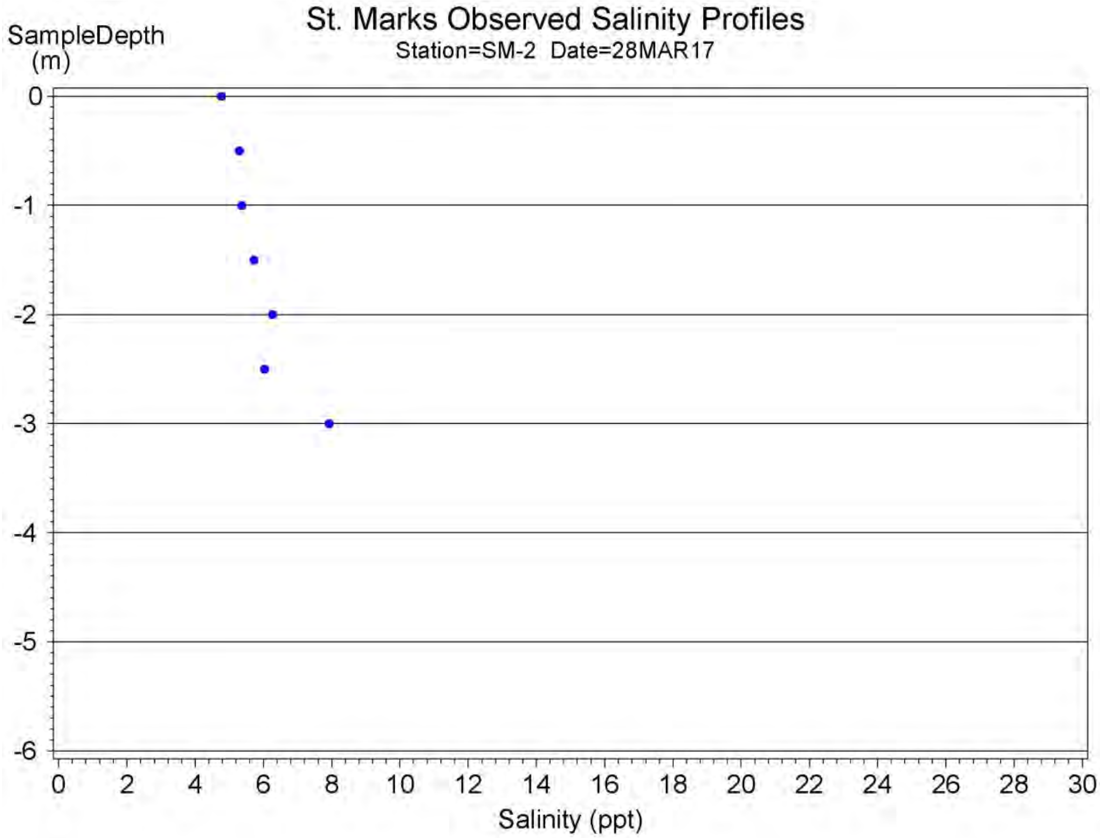
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-2 Date=28MAR17
SampleDepth
(m)
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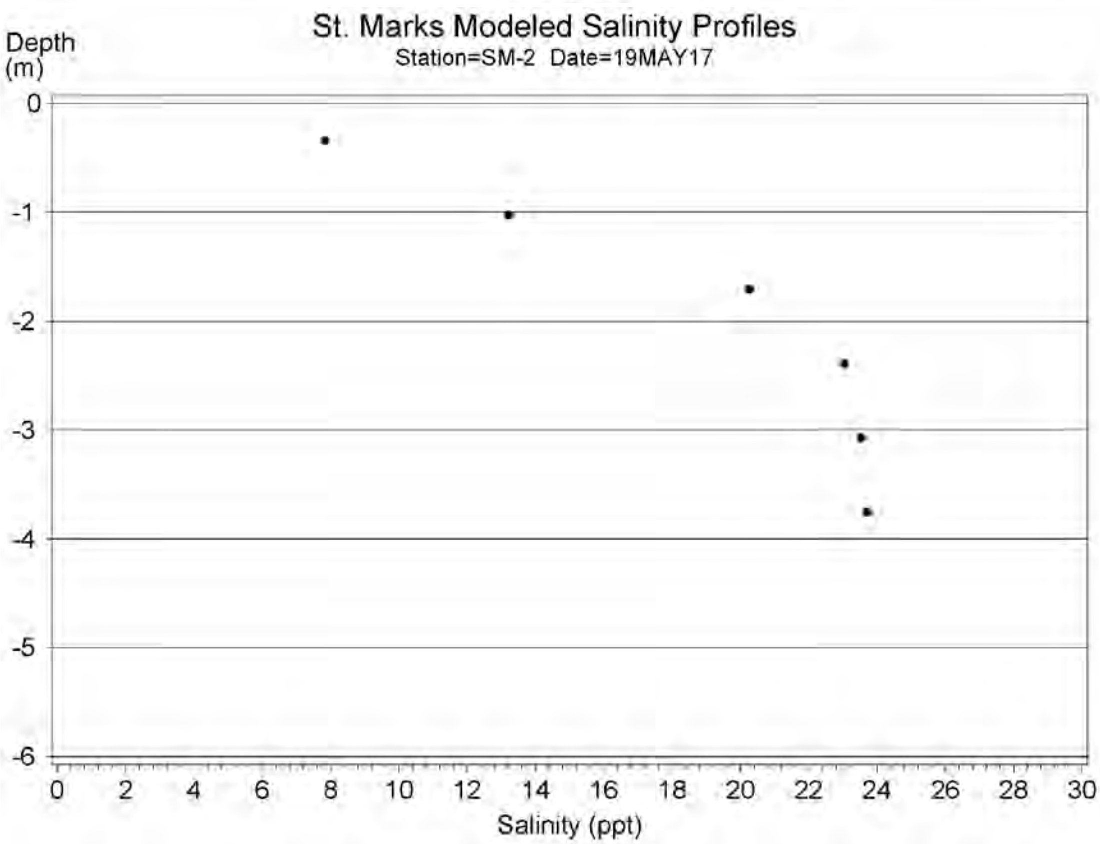
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-2 Date=19MAY17
Depth
(m)
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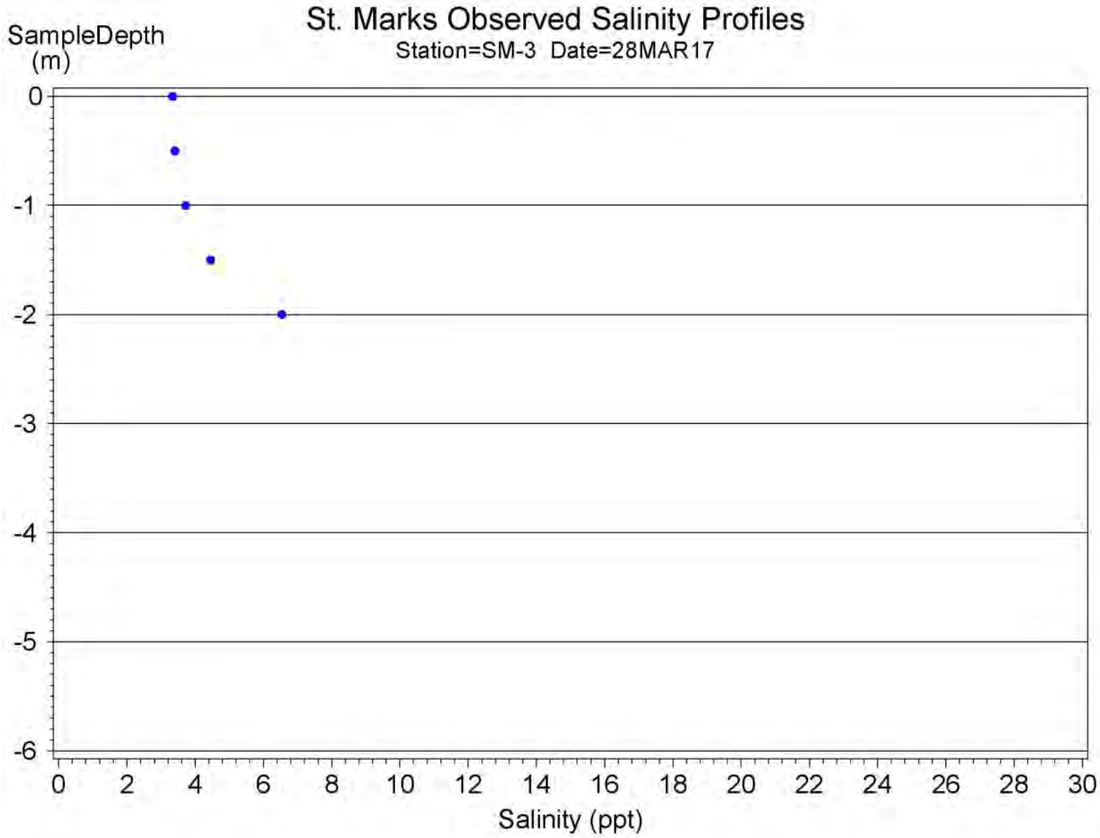
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)



St. Marks Observed Salinity Profiles
Station=SM-3 Date=28MAR17
SampleDepth (m)
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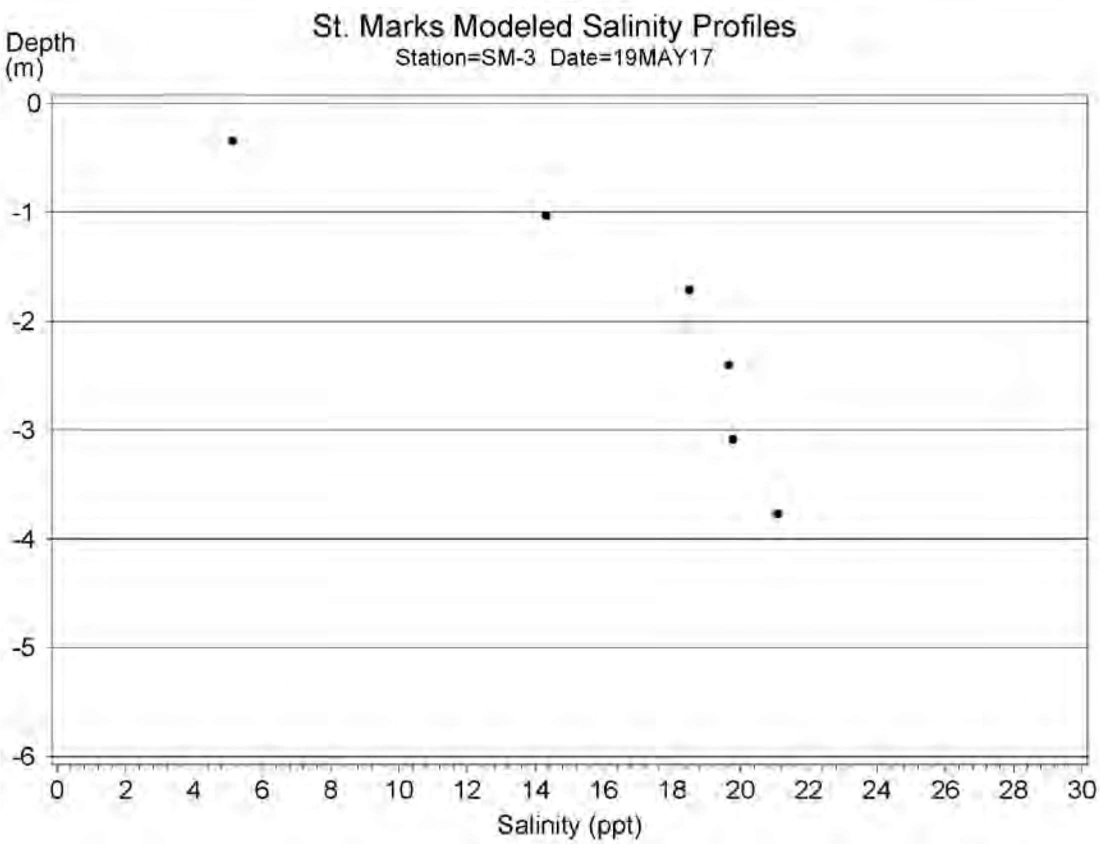
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)



St. Marks Modeled Salinity Profiles
Station=SM-3 Date=19MAY17
Depth (m)
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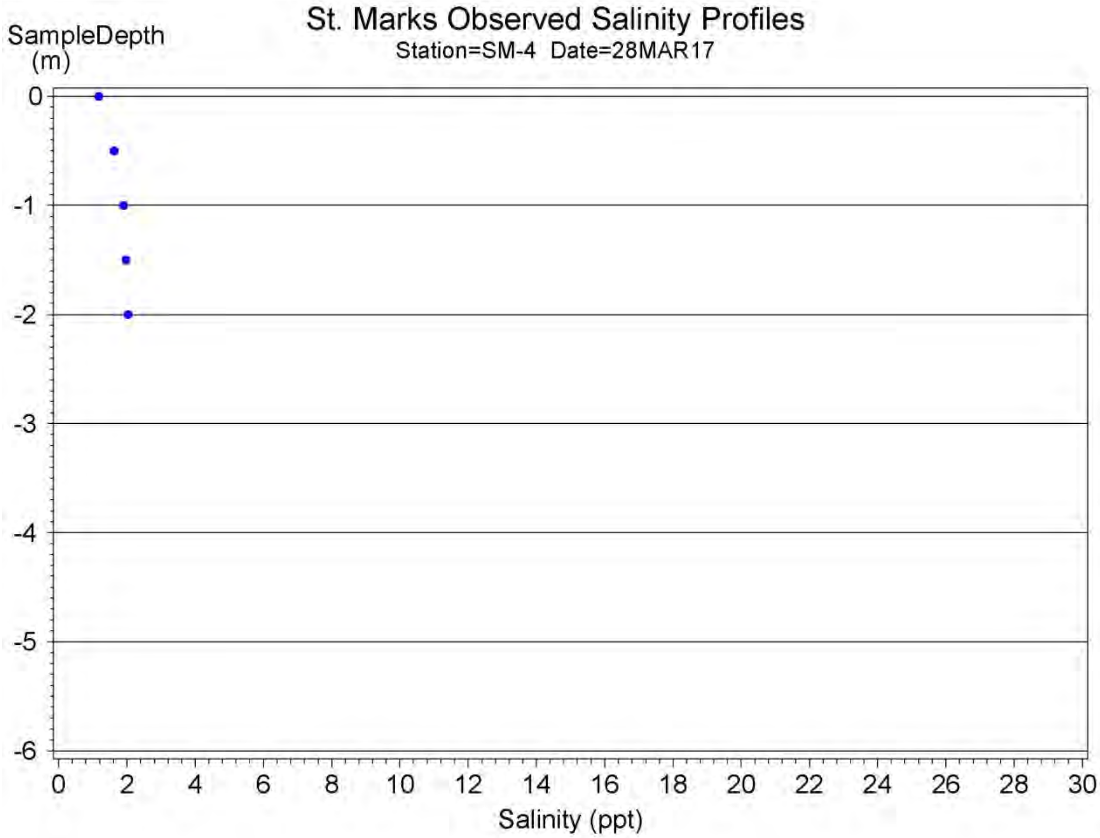
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-4 Date=28MAR17
SampleDepth (m)
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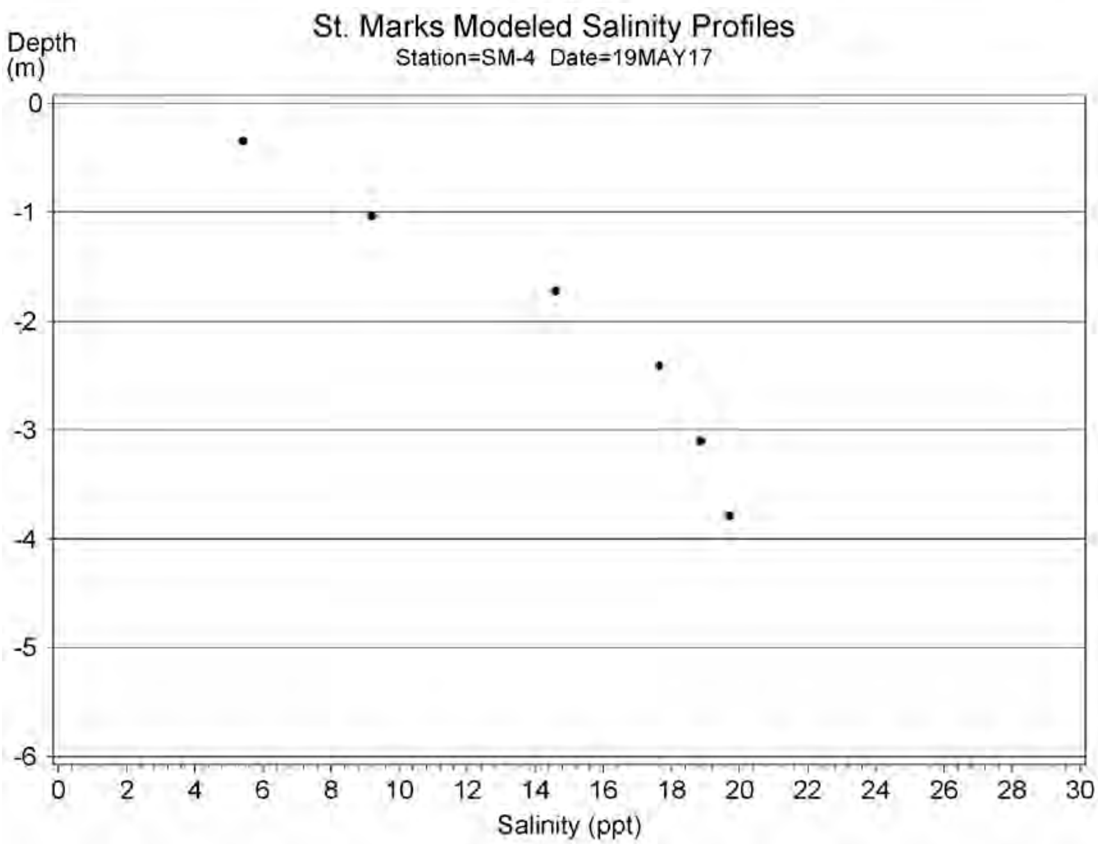
-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)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Station=SM-4 Date=19MAY17
Depth (m)
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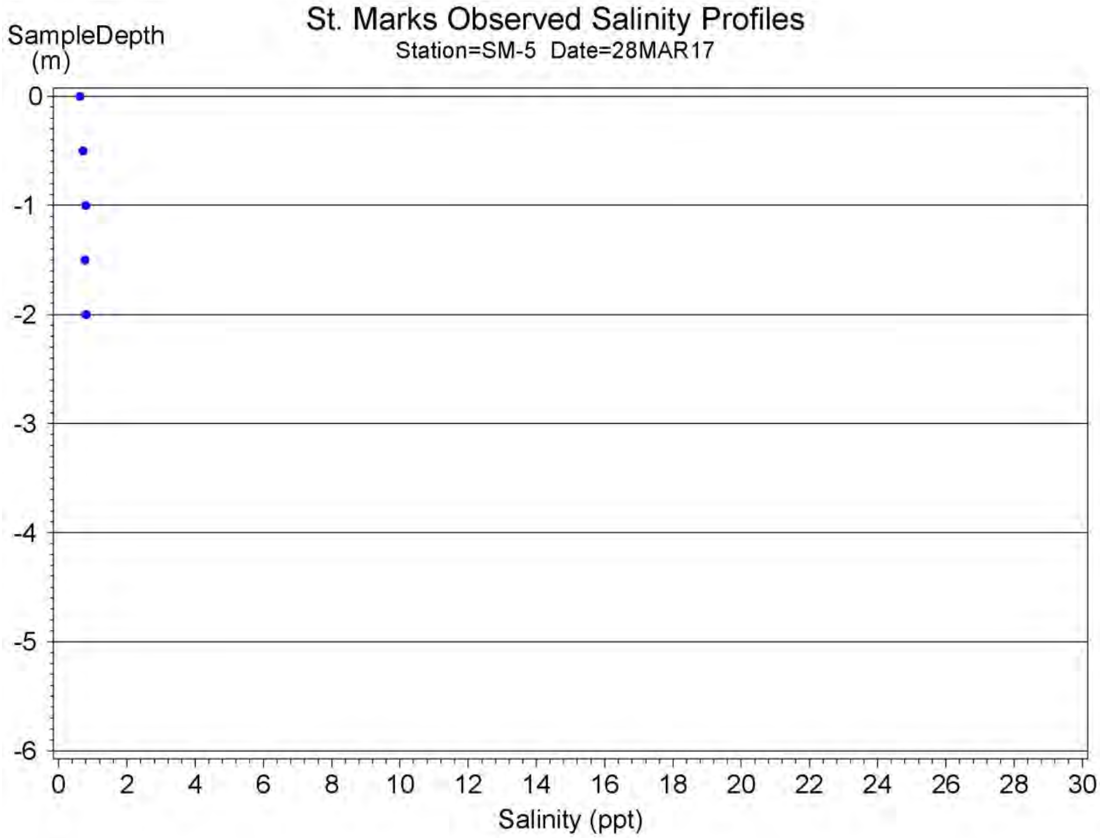
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
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SampleDepth (m)
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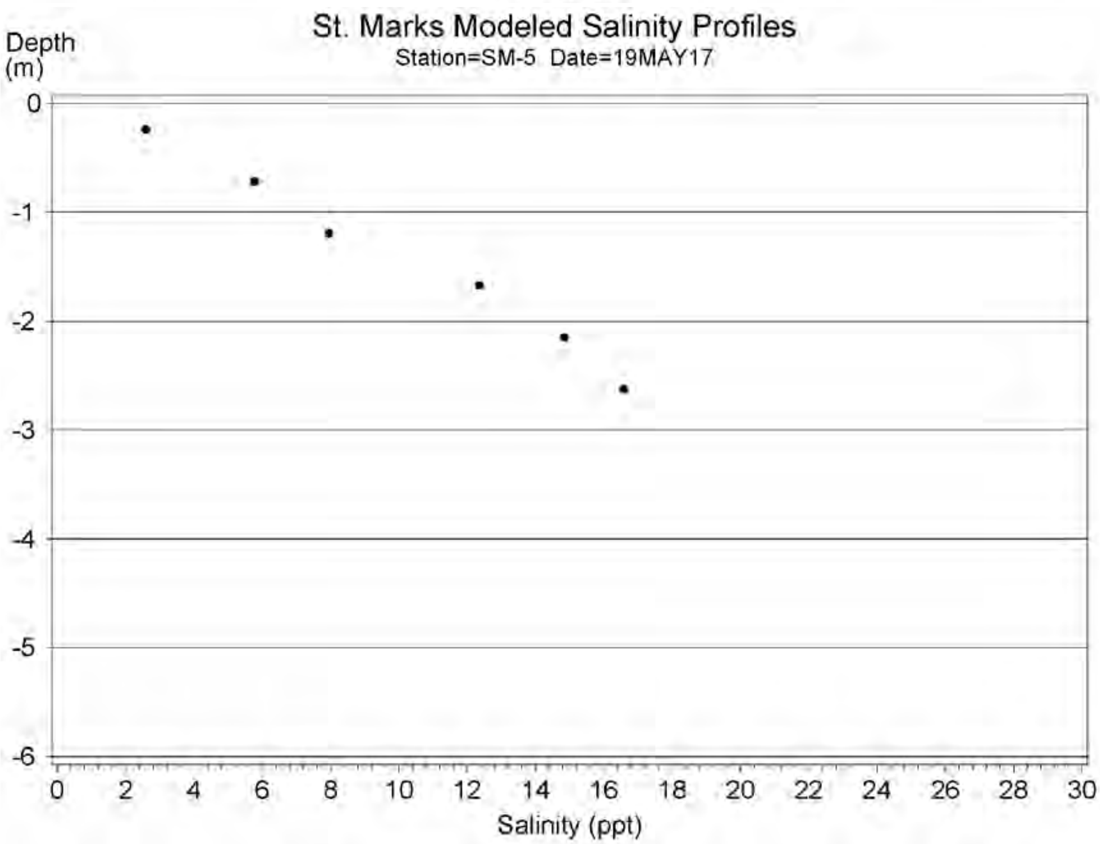
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)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Depth (m)
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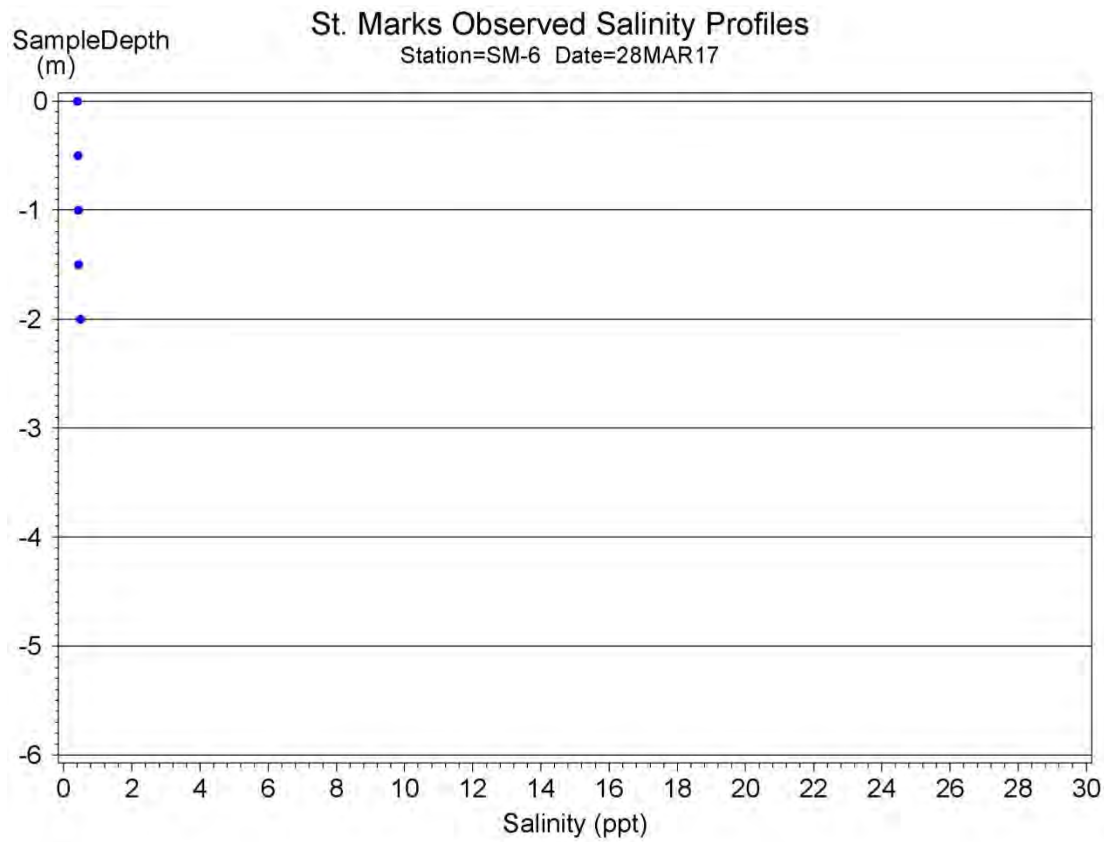
Salinity (ppt)



St. Marks Observed Salinity Profiles
Station=SM-6 Date=28MAR17
SampleDepth
(m)
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-3
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-5
-6
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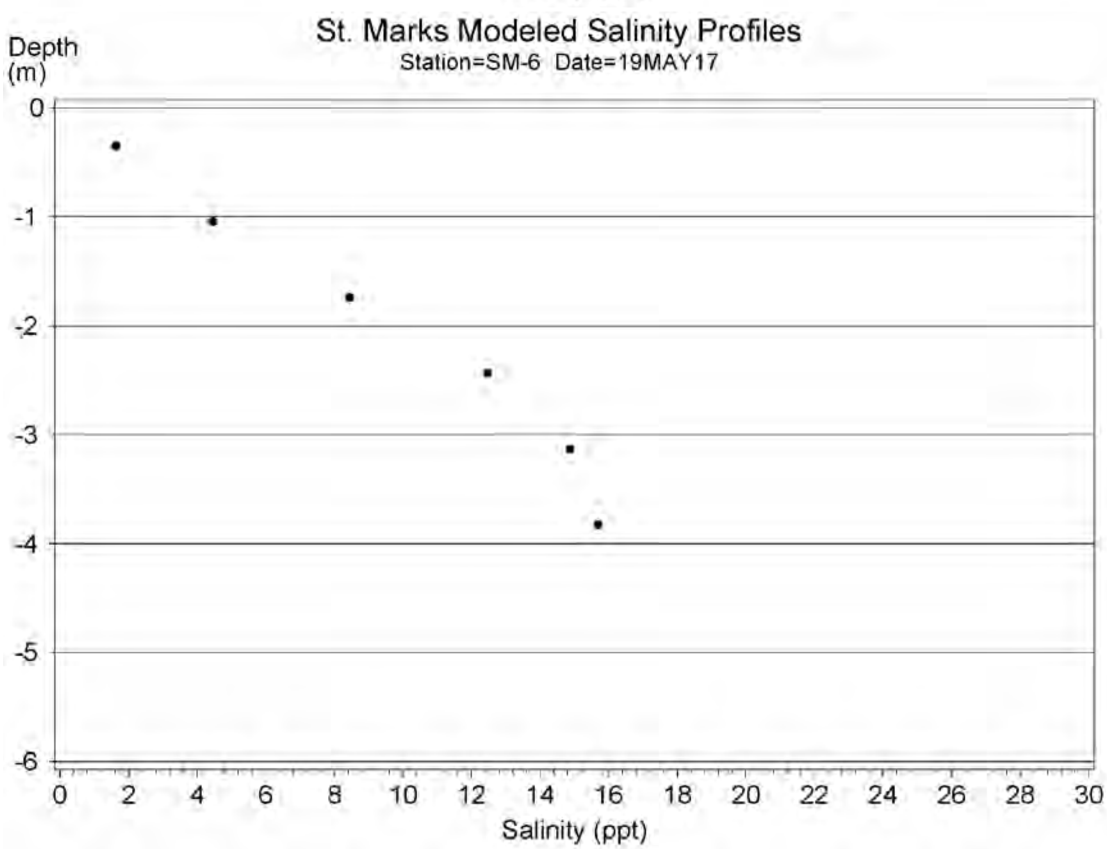
Salinity (ppt)



St. Marks Modeled Salinity Profiles
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Depth
(m)
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-5
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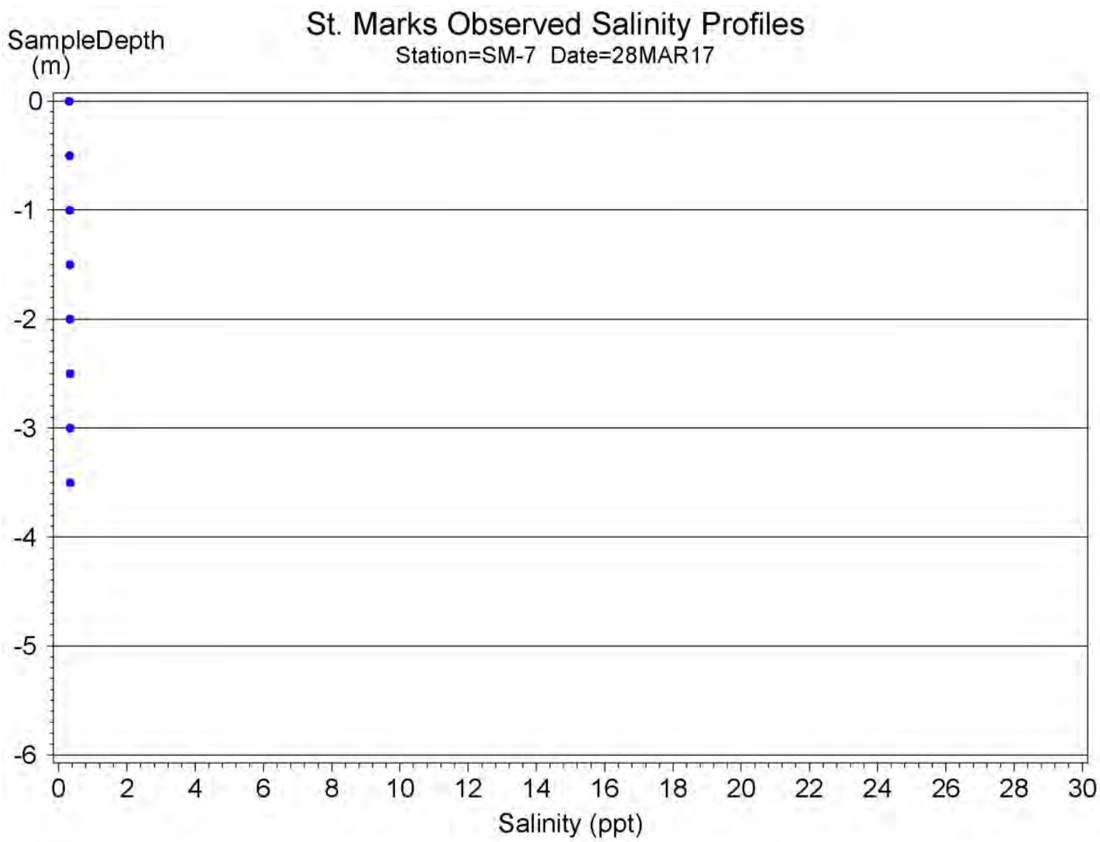
Salinity (ppt)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SampleDepth (m)
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-6
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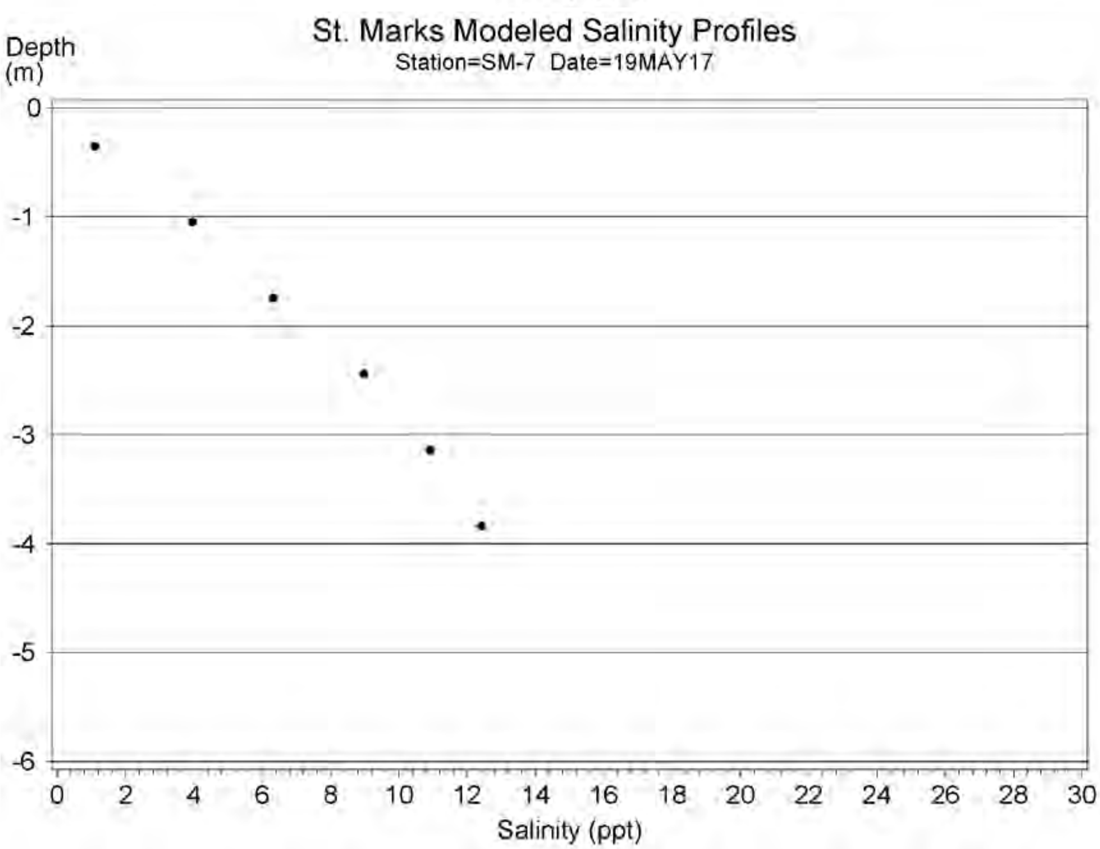
Salinity (ppt)


St. Marks Modeled Salinity Profiles
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Depth (m)
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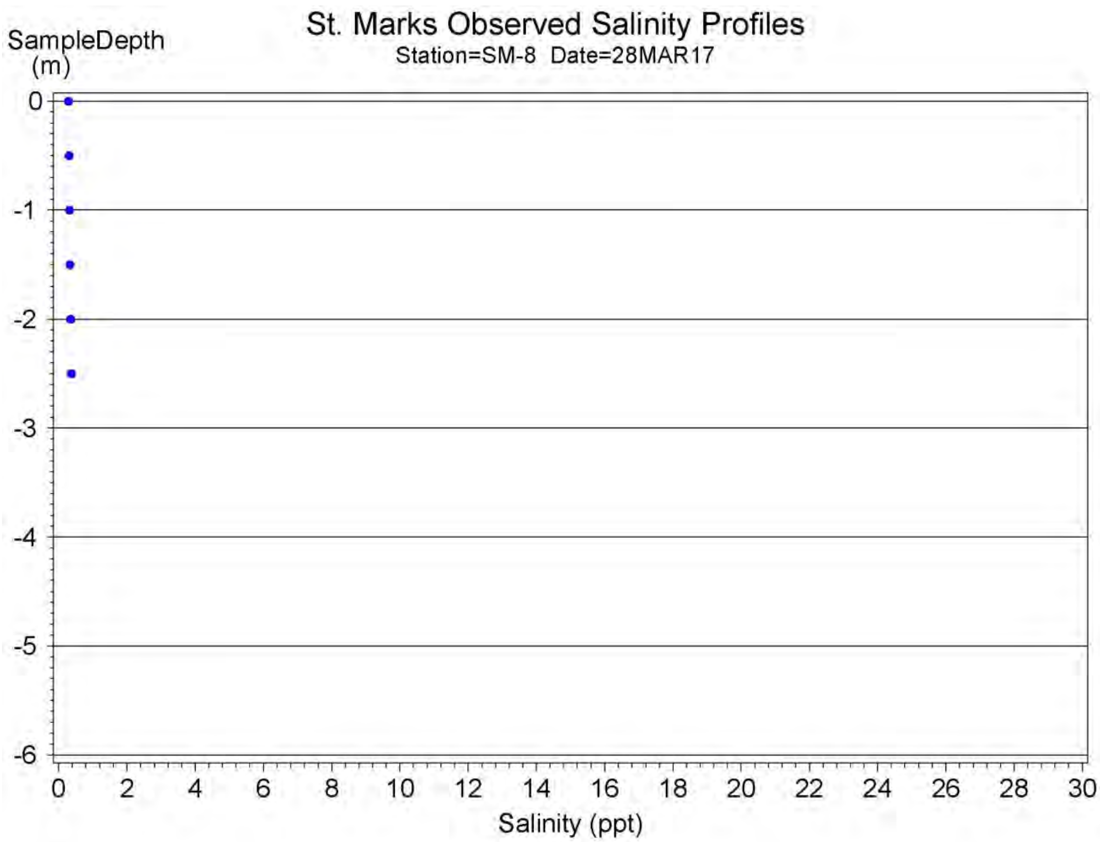
Salinity (ppt)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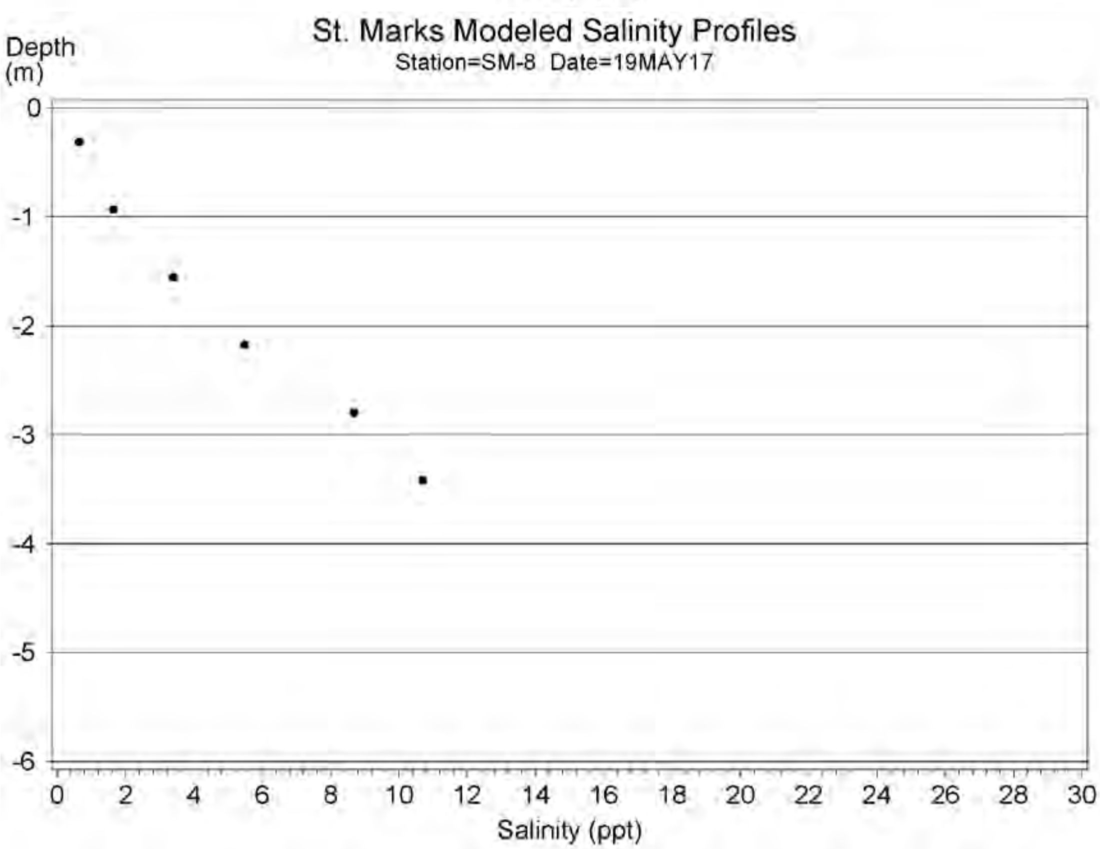
Salinity (ppt)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Depth (m)
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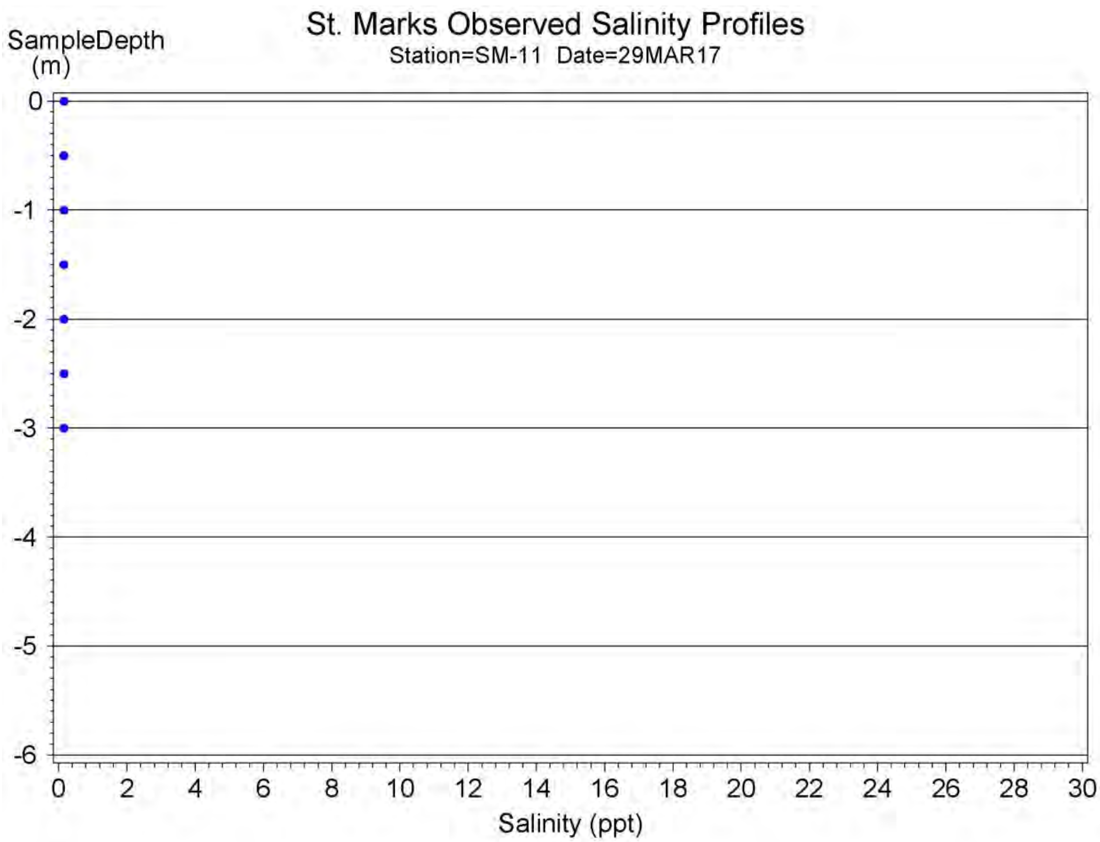
Salinity (ppt)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-6
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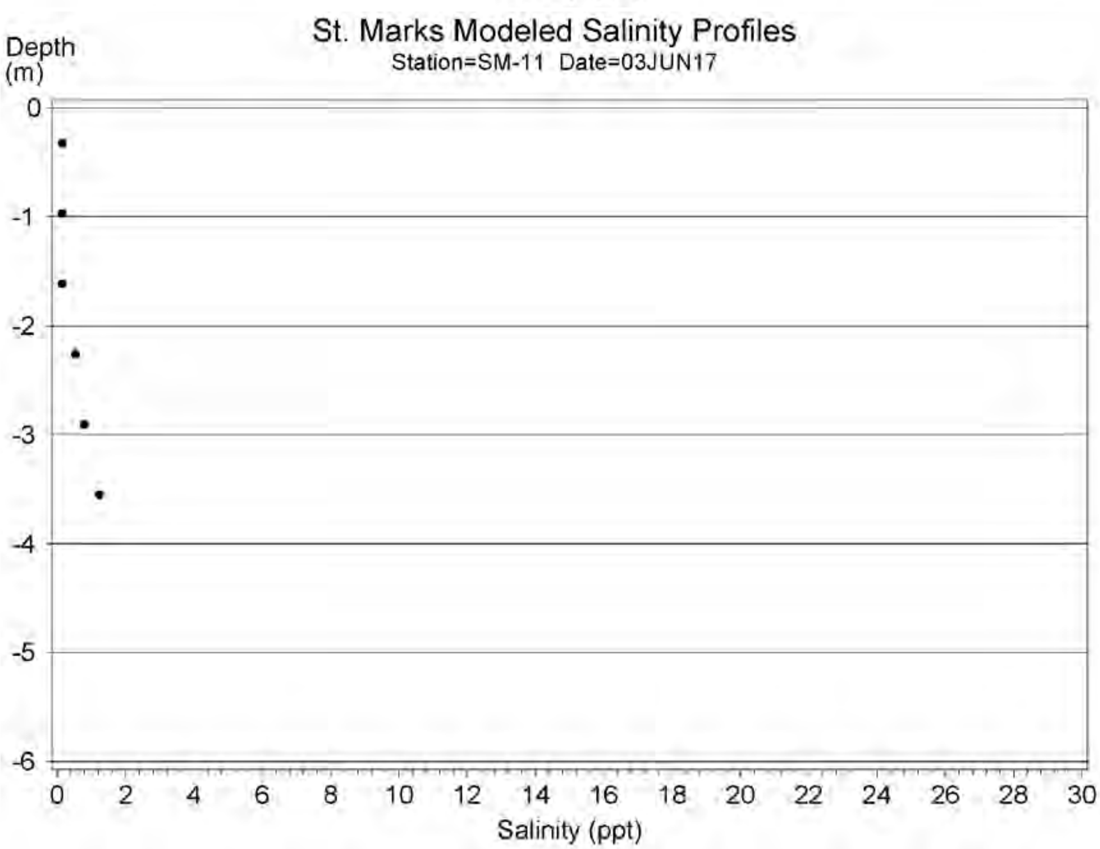
Salinity (ppt)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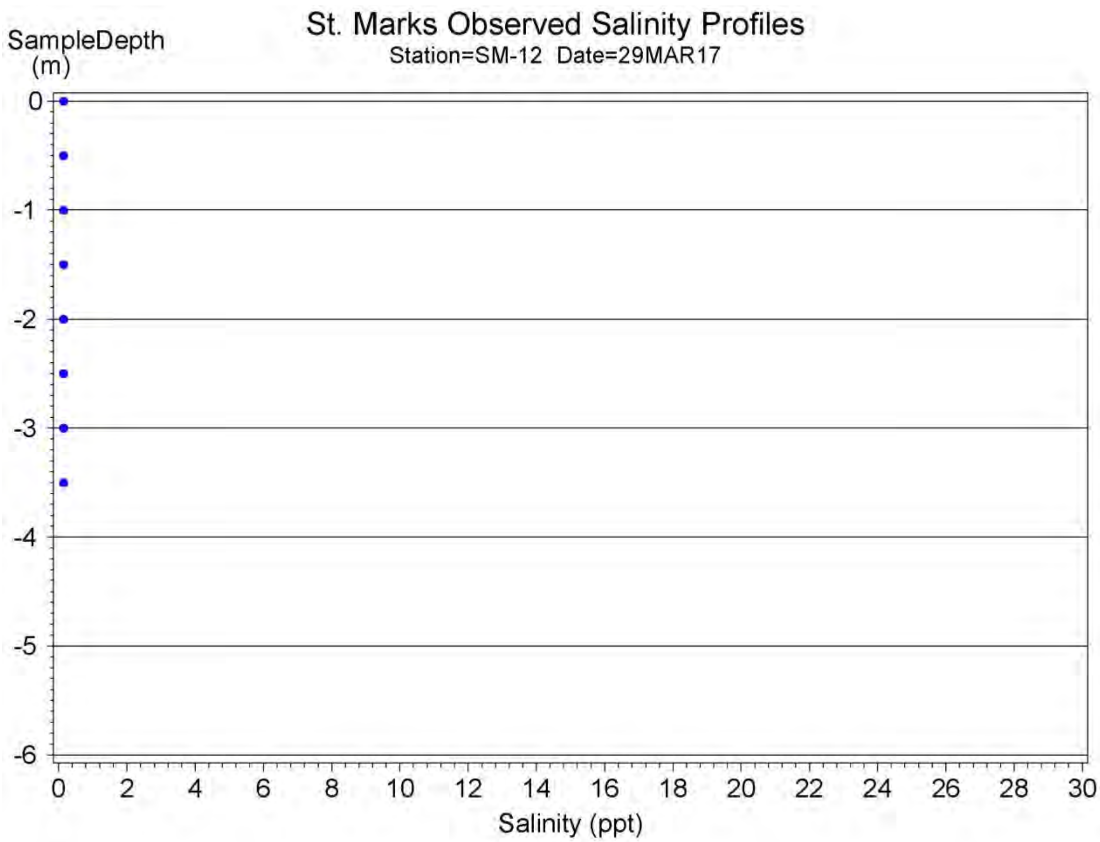
Salinity (ppt)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SampleDepth (m)
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-4
-5
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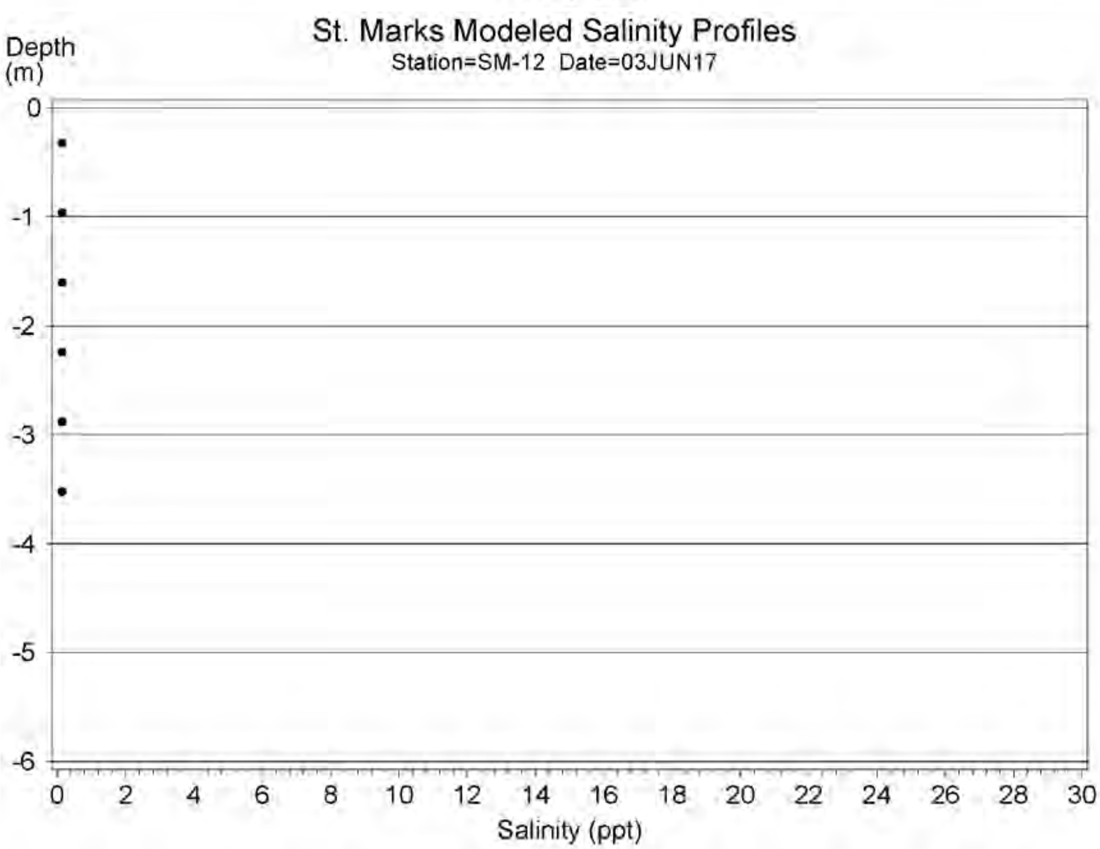
Salinity (ppt)


St. Marks Modeled Salinity Profiles
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-5
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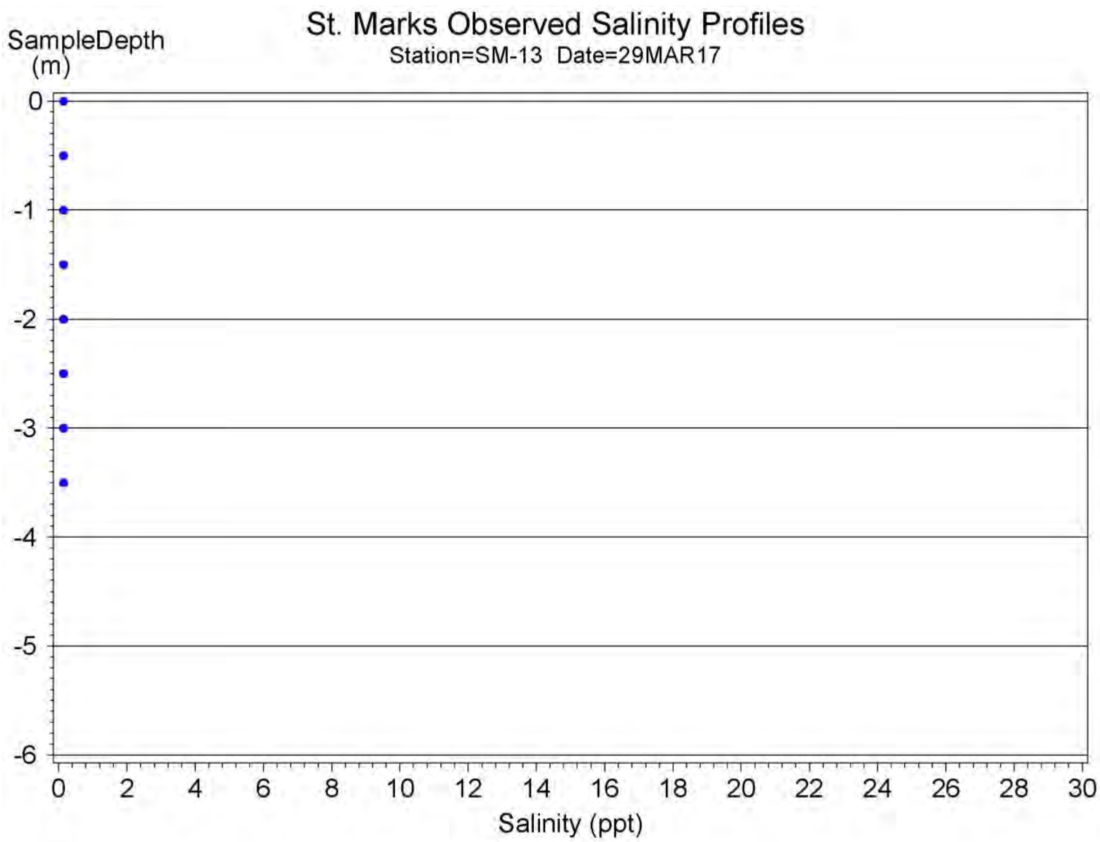
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)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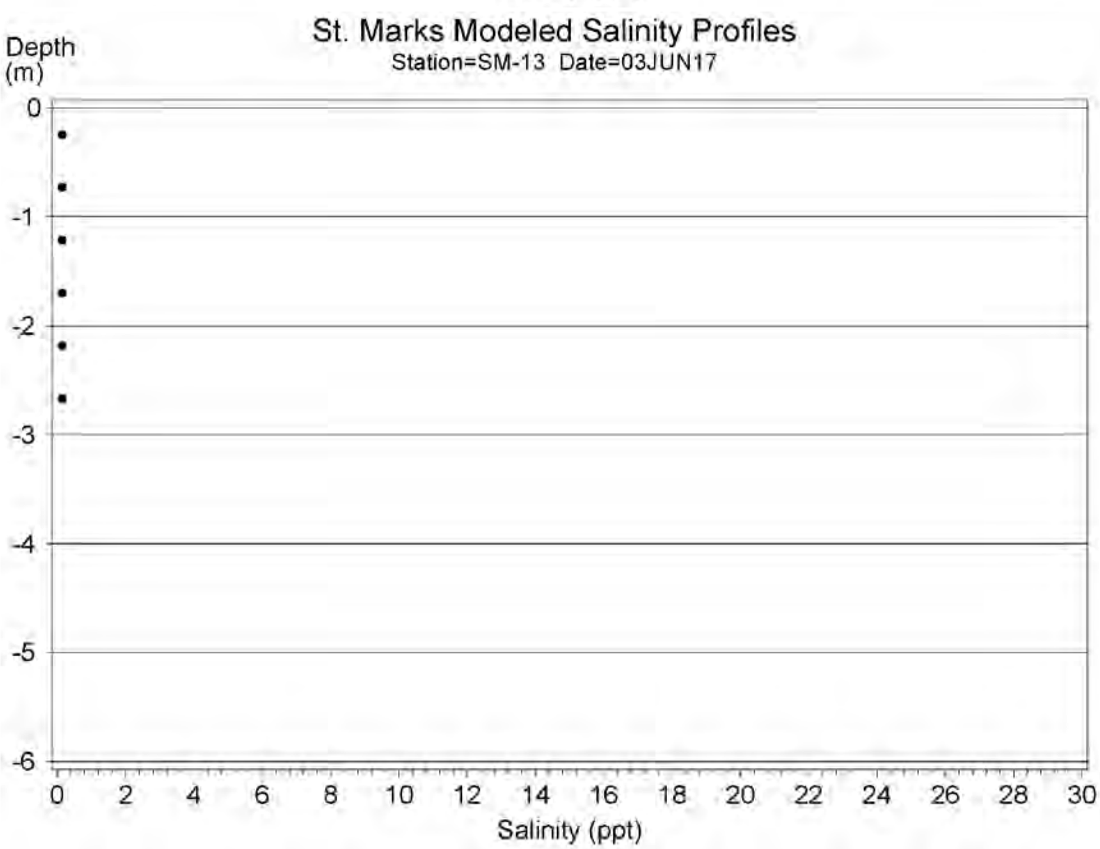
Salinity (ppt)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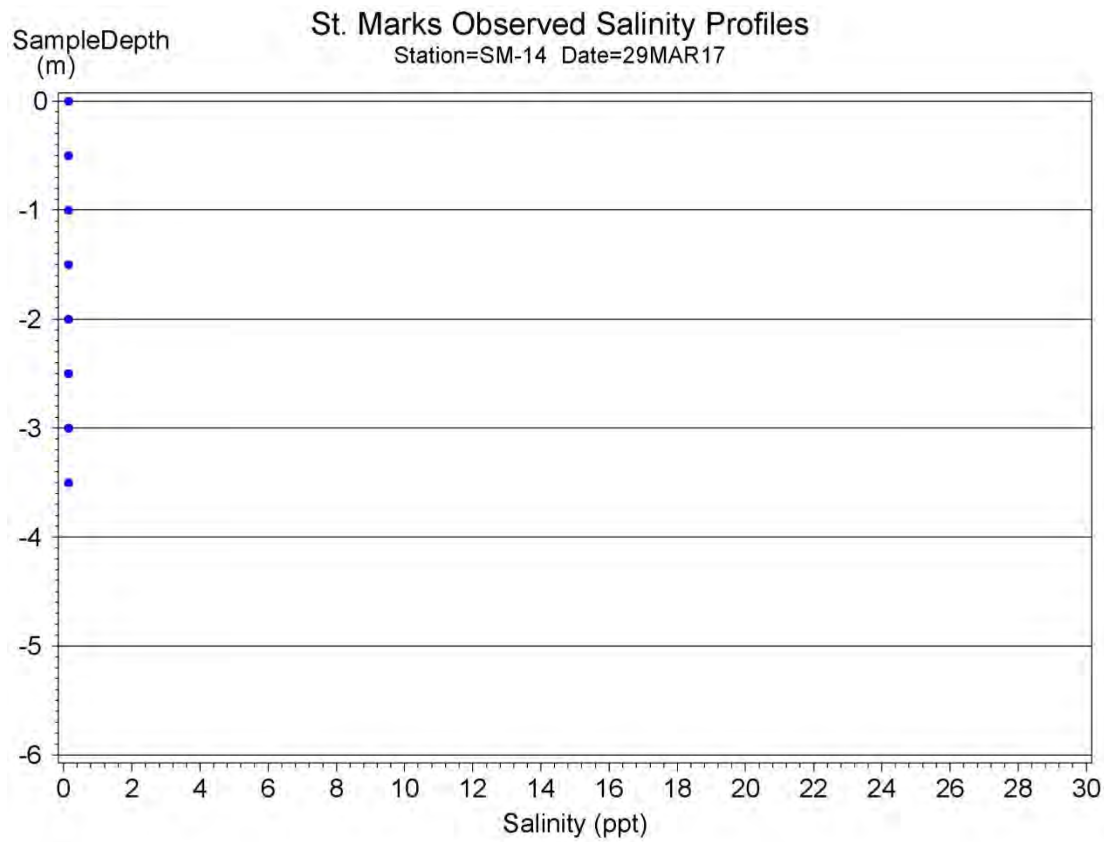
Salinity (ppt)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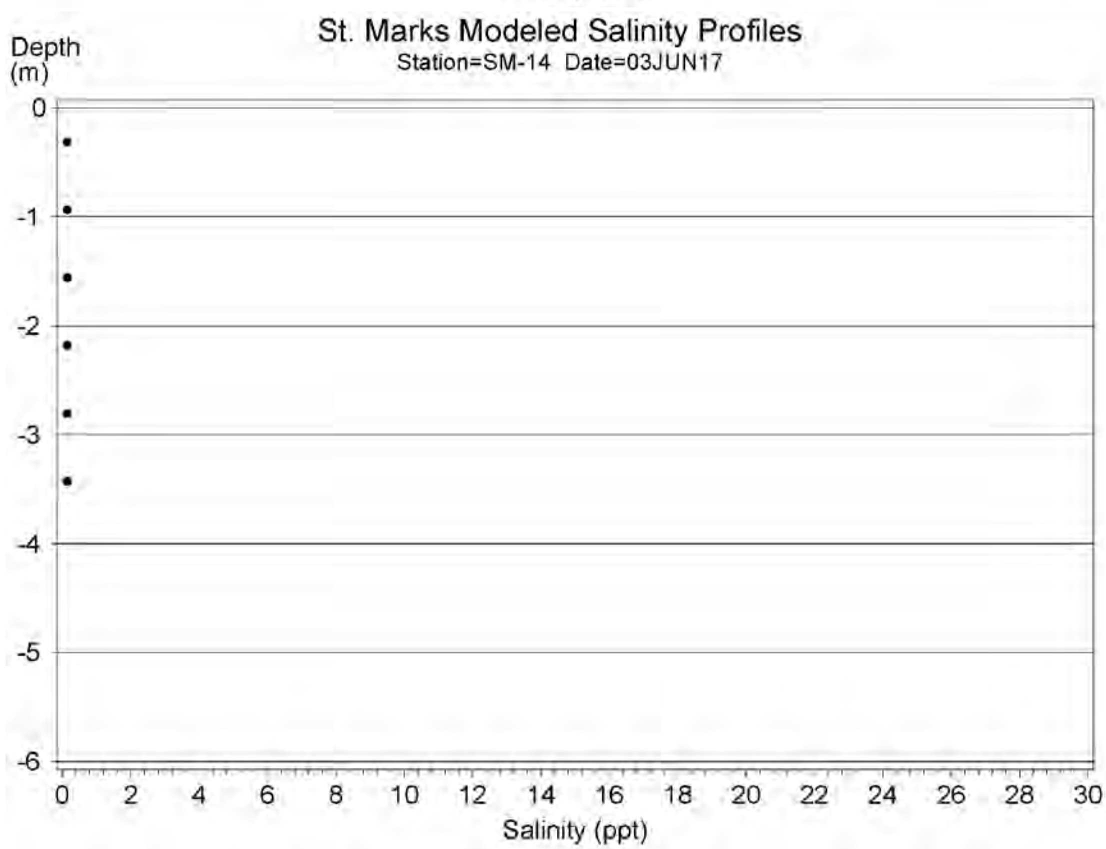
Salinity (ppt)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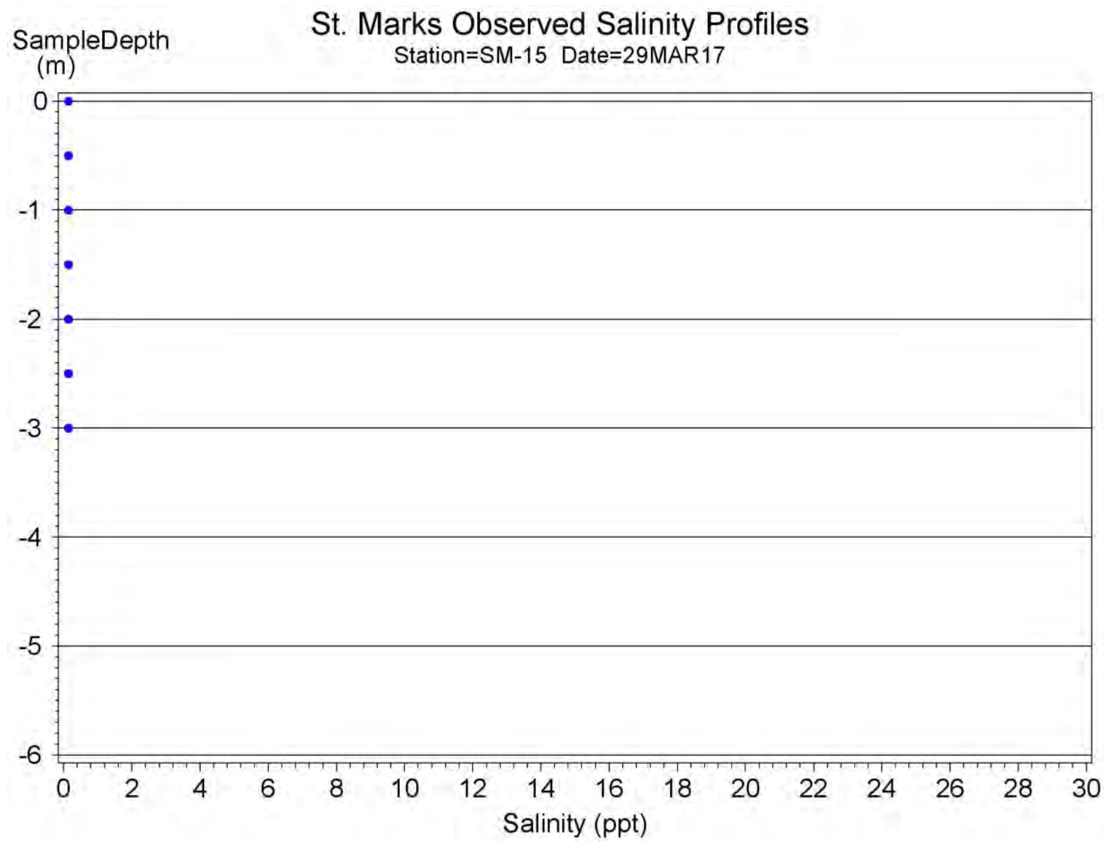
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)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SampleDepth (m)
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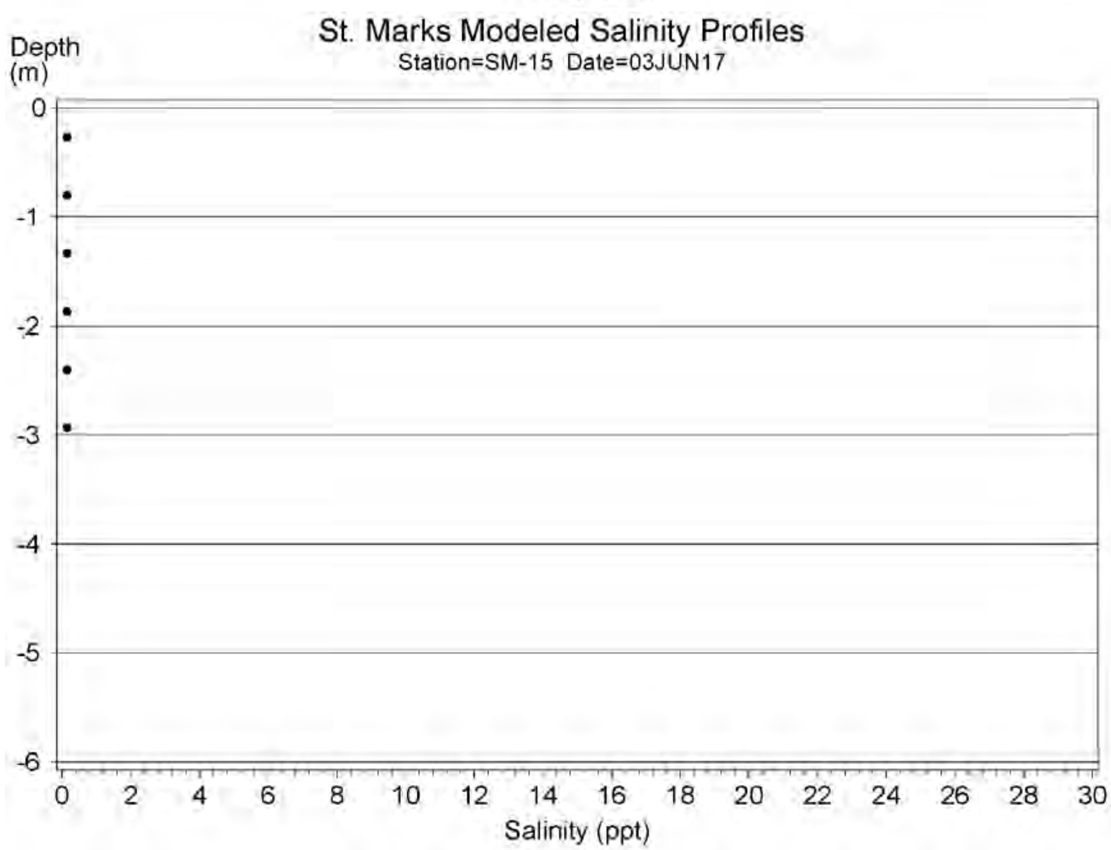
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)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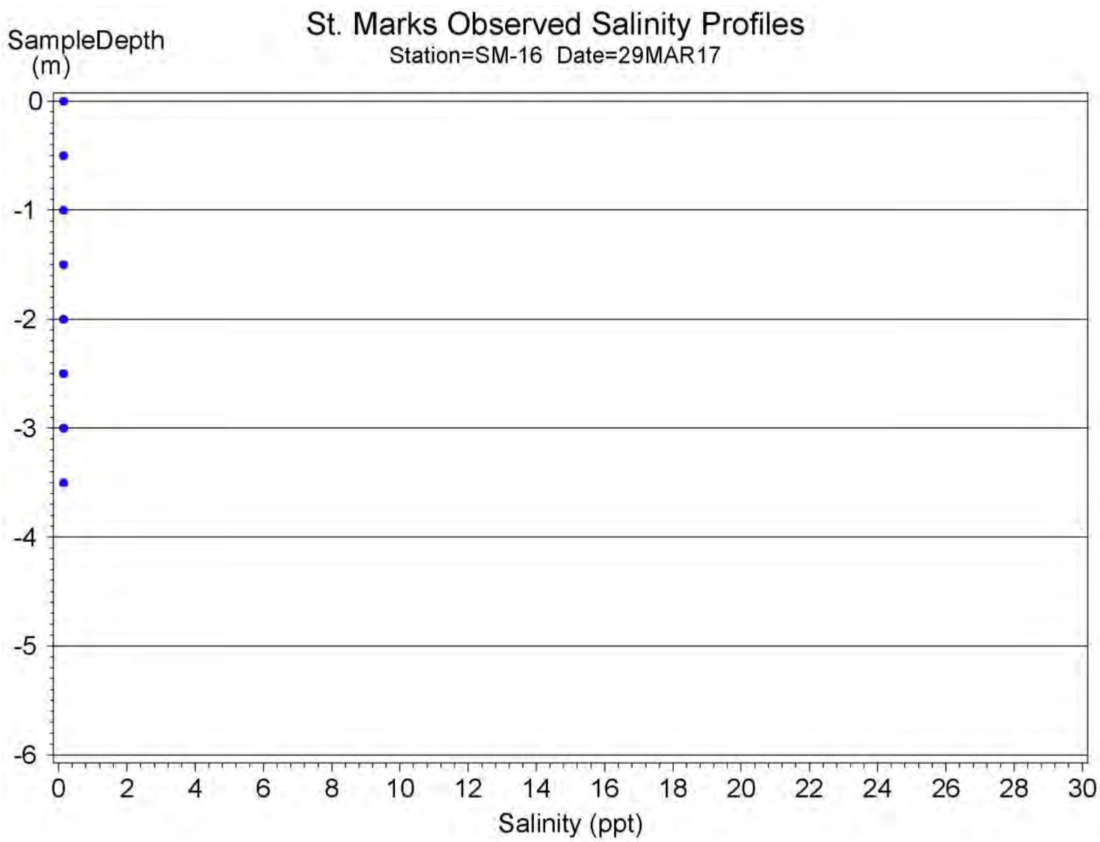
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)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SampleDepth (m)
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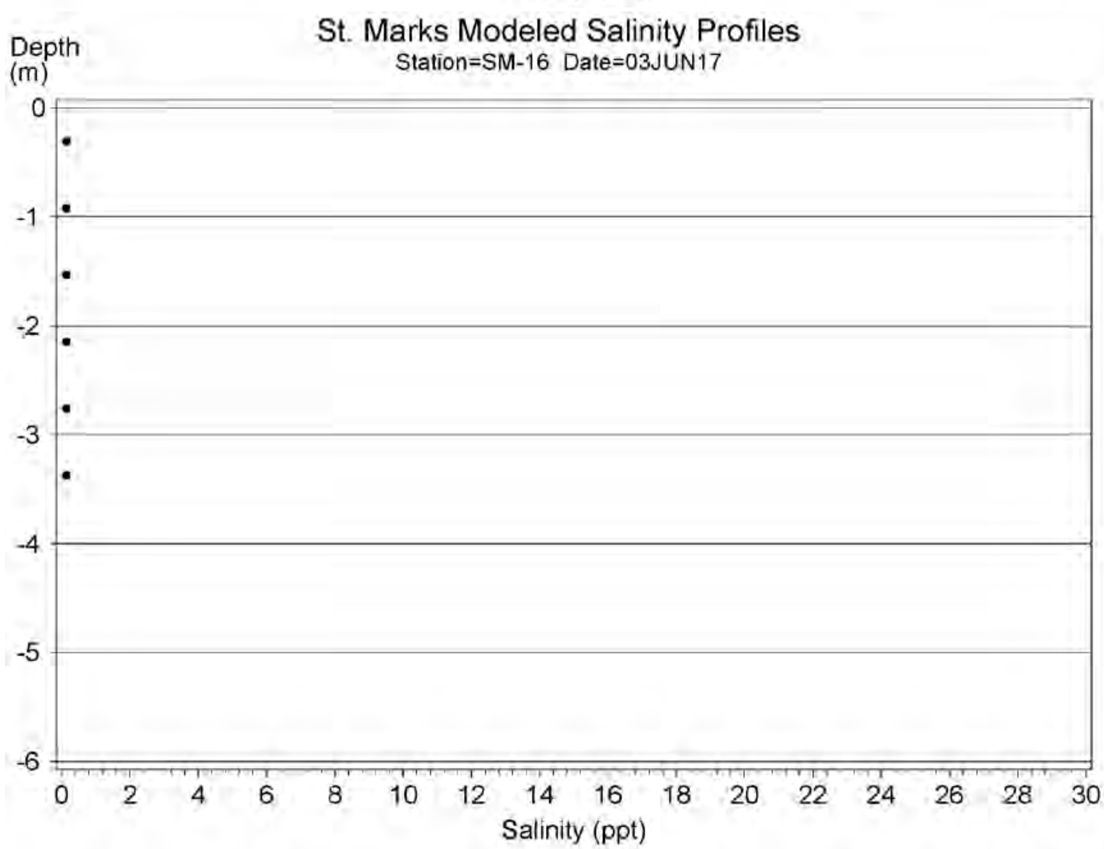
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)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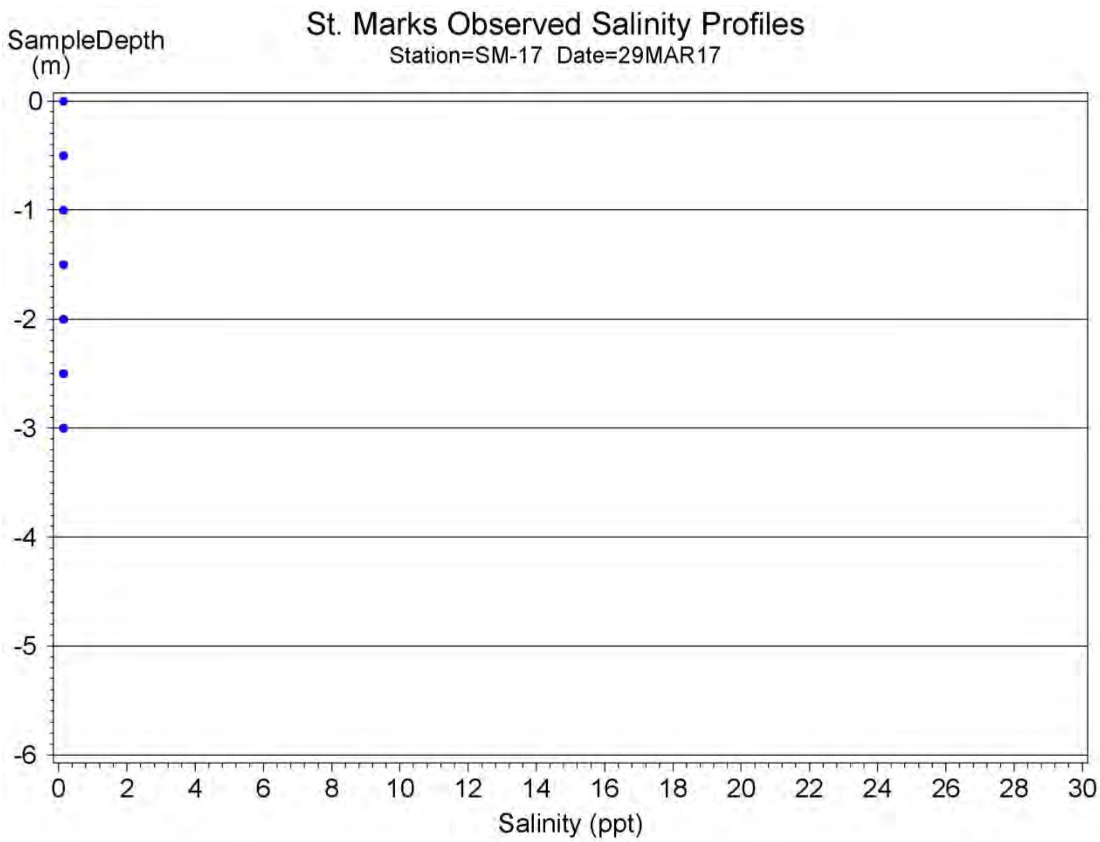
Salinity (ppt)


St. Marks Observed Salinity Profiles
Station=SM-17 Date=29MAR17
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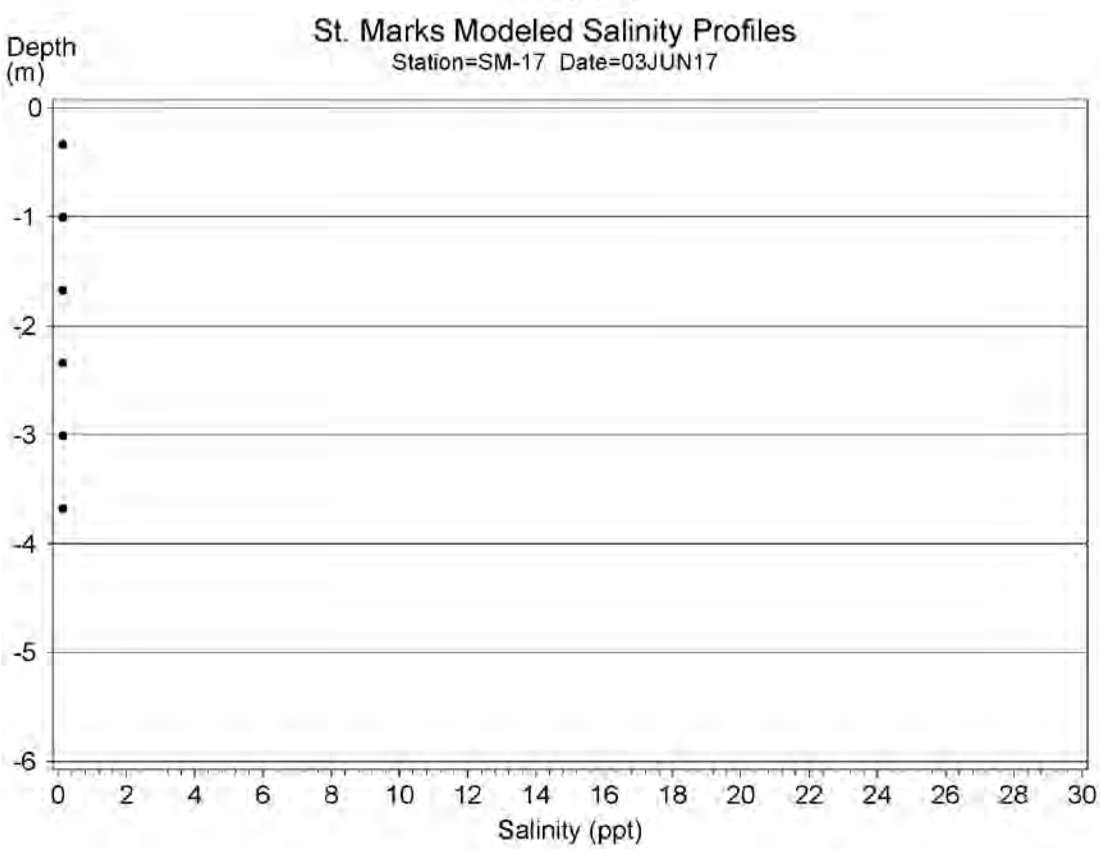
Salinity (ppt)


St. Marks Modeled Salinity Profiles
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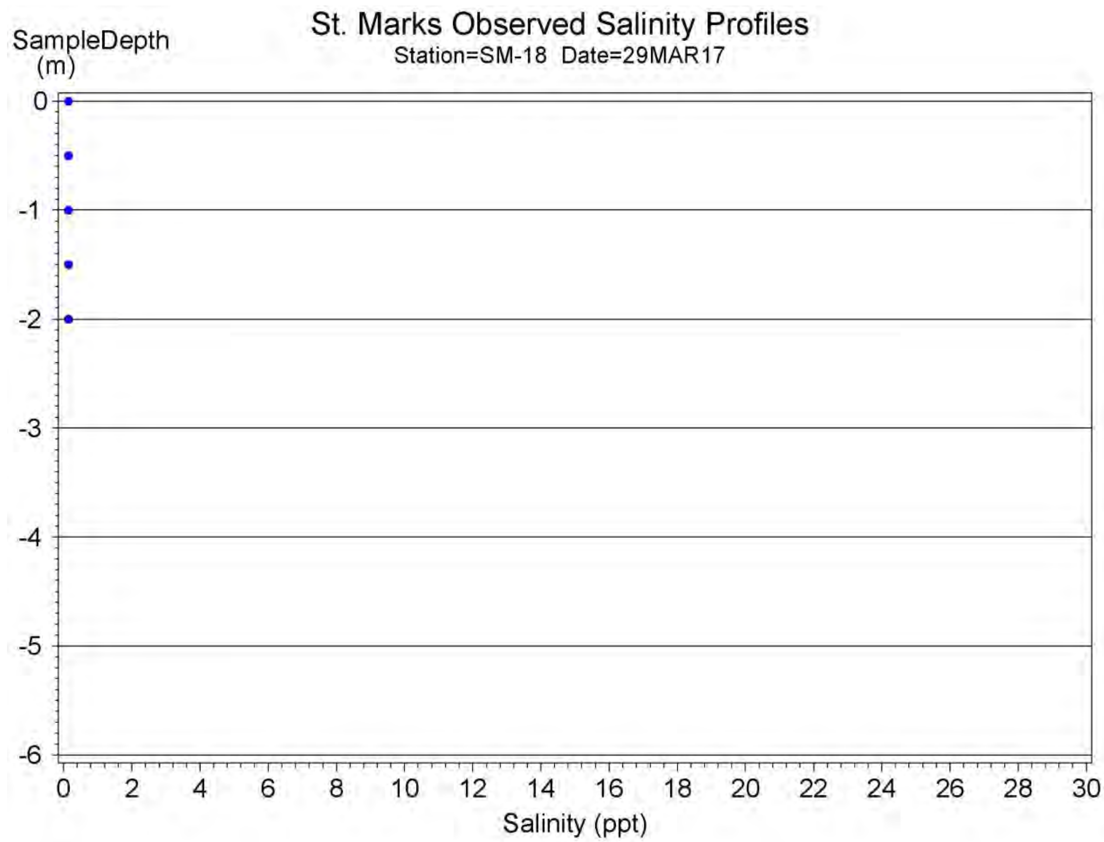
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)


St. Marks Observed Salinity Profiles
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SampleDepth (m)
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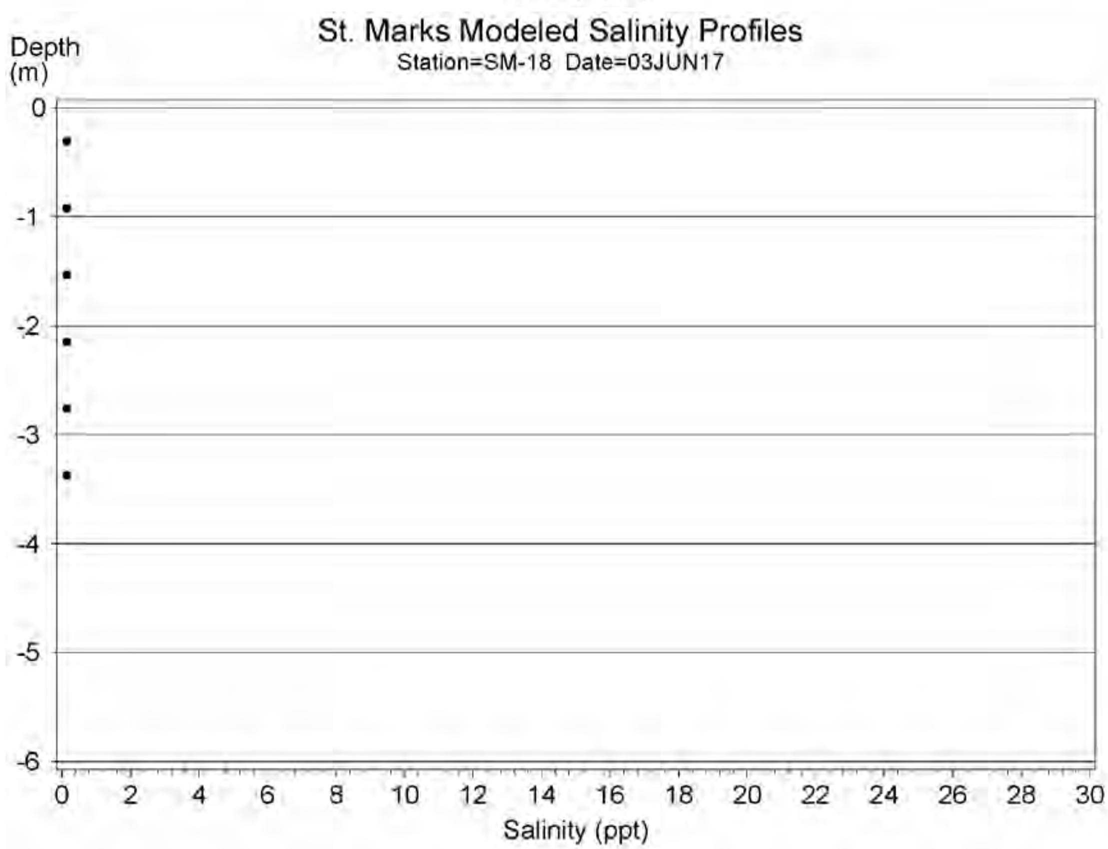
Salinity (ppt)


St. Marks Modeled Salinity Profiles
Station=SM-18 Date=03JUN17
Depth (m)
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-1
-2
-3
-4
-5
-6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Salinity (ppt)

B

Hydrodynamic Model Evaluation of Minimum Flow Scenarios for the St. Marks River Rise

Prepared for:
Northwest Florida Water Management District
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Havana, FL 32333-4712

Prepared by:
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St. Petersburg, FL 33704

May 2018

1 Introduction and Objectives

The Northwest Florida Water Management District (District) is developing minimum flows for the St. Marks River Rise (River Rise). The minimum flows will address protection of water resources affected by reduced spring flows, including those in the downstream freshwater and estuarine reaches of the St. Marks River. This current document provides the results of a series of Tasks, part of Task Order (TO) #5, directed at evaluating potential spring flow reduction scenarios using the calibrated hydrodynamic model of the St. Marks and Wakulla rivers previously developed, in aid of developing a minimum flow for the River Rise.

Modeling tools have been developed to evaluate and predict the effects of various flow reduction scenarios on selected water resource values (WRVs) in the St. Marks River between the River Rise and the confluence with the Wakulla River. These models include a mechanistic model for simulation of the hydrodynamic responses (salinity, temperature, water velocities, water surface elevation) (Janicki Environmental, 2018a) to aid in determination of the minimum flows for the River Rise spring discharge. This model is used to derive values for metrics selected as protective of the Estuarine Resources WRVs from baseline and reduced spring flow scenarios. Comparison of the baseline model results with those from reduced spring flow scenarios allows determination of the effects on estuarine communities resulting from flow reductions.

To determine the effects of spring flow reductions on WRV metrics, a long-term baseline spring flow record reflecting conditions unimpacted by consumptive uses was developed for the period 1956-2017 (Janicki Environmental, 2018b). A subset of this record representative of the flow distribution over the entire period of record was identified and used to develop baseline and spring flow reduction scenario results related to the Estuarine Resources WRV. The selected spring flow record was for the period May 1, 1997 through May 31, 1999 (Janicki Environmental, 2018b). This period is henceforth termed the baseline period, and the model run for this period with observed conditions flows and other observed inputs is termed the baseline scenario.

This document reports the results of the work efforts completed for TO#5, as follows:

- Implement the calibrated EFDC hydrodynamic model of the St. Marks and Wakulla rivers (Janicki Environmental, 2018a) for the baseline flow period selected for evaluation (Janicki Environmental, 2018b), and implement River Rise spring flow reduction scenarios to allow comparison of resulting WRV metrics values;
- Implement additional scenarios as directed by the District based on findings from initial set of River Rise spring flow reduction runs, with evaluation of resultant WRV metrics values for comparison to those from the baseline run.
- Provide technical support to the District in the development of the minimum flows and reporting, including tables and graphics as needed for minimum flow report finalization.

2 Description of Baseline Spring Flow Scenario

As part of the hydrodynamic model calibration effort, model input datasets were developed which provided boundary conditions for the model. These datasets included meteorological information, downstream water surface elevation, downstream salinity and temperature, and fresh water inflows to the system (Janicki Environmental, 2018a). These same data types were necessary for implementing the calibrated hydrodynamic model for the Baseline period of May 1, 1997 - May 31, 1999. The data used as input for the baseline and other scenarios are provided as time series plots over the model period, with the finalized datasets provided as Excel files or CSV files in the accompanying model file set delivered with this documentation. Brief summaries of each dataset are provided in the following.

The data used to set up model boundary conditions for the baseline period include the following:

- Meteorology (model input file ASER.INP): Hourly data for air temperature, atmospheric pressure, relative humidity, rainfall, solar radiation, and cloud cover were obtained from the National Weather Service Tallahassee Regional Airport site. Daily evapotranspiration data were obtained from the FAWN IFAS site at Ocklawaha, FL. The site used for daily evapotranspiration data for the calibration effort was the IFAS FAWN Monticello site, but data records from this site do not include the baseline period; the next closest site with available data is the Ocklawaha site. The locations of the various data collection sites providing data for the baseline period model boundary conditions are provided in Figure 1. Time series plots of the meteorological data for the baseline period (5/01/97-5/31/99) are provided in Figures 2-8.

Figure 1. Locations of data collection sites for boundary condition information: meteorology (Tallahassee Regional Airport and IFAS FAWN Ocklawaha), flow gages (USGS), and winds (NOAA NDBC Keaton Beach).

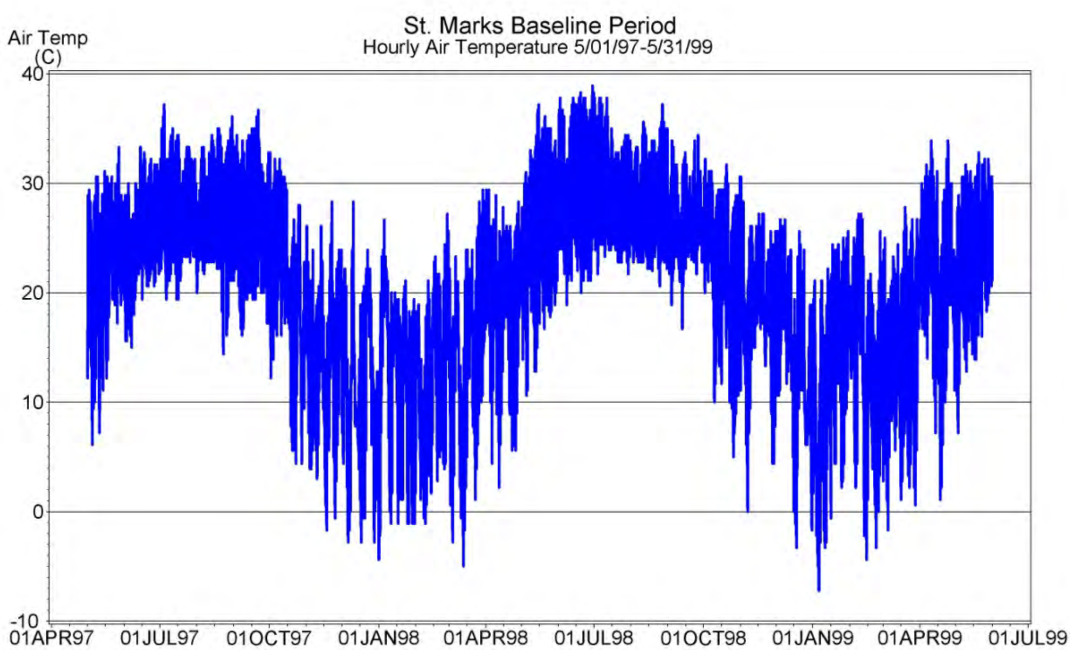

Figure 2. Hourly air temperature from Tallahassee Regional Airport.

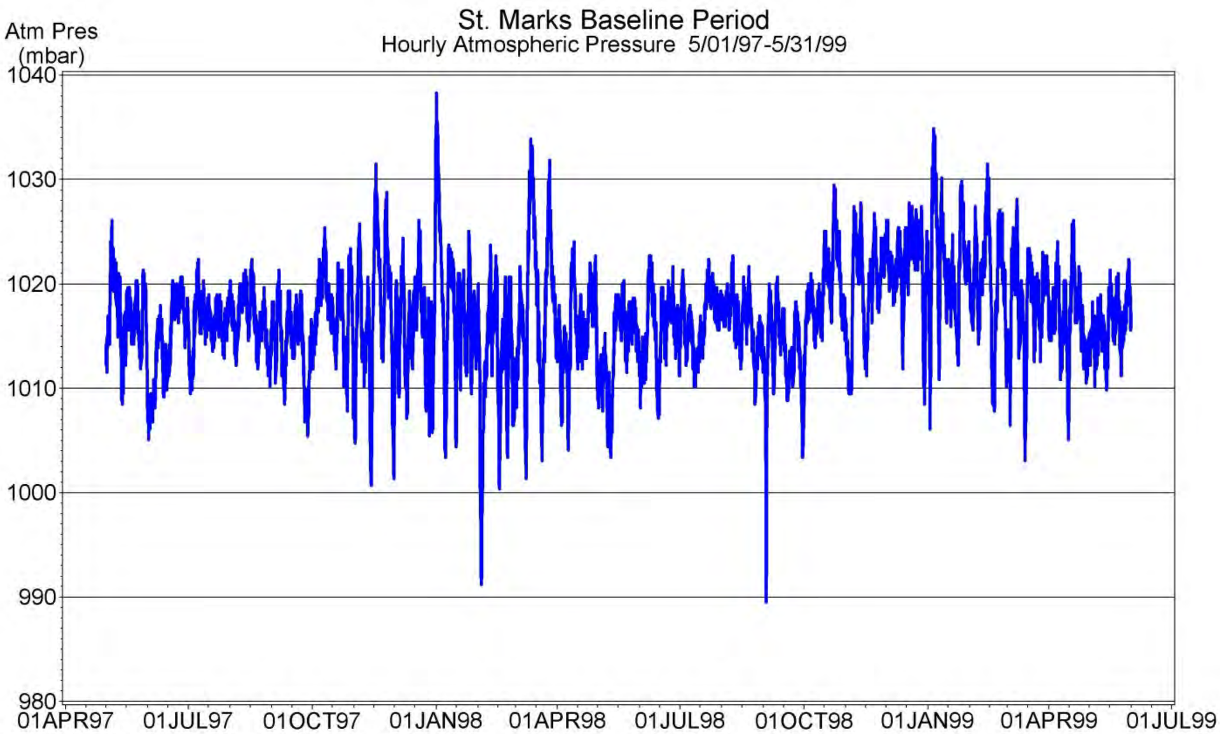

Figure 3. Hourly atmospheric pressure from Tallahassee Regional Airport.

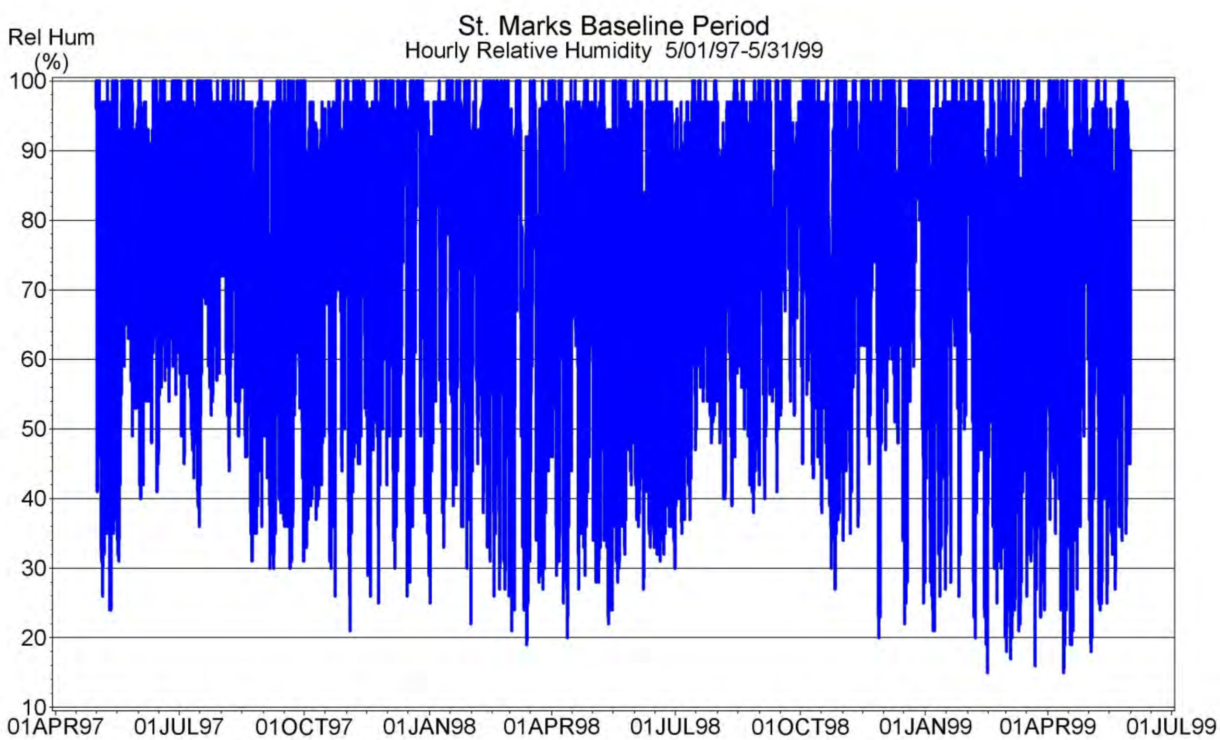

Figure 4. Hourly relative humidity from Tallahassee Regional Airport.

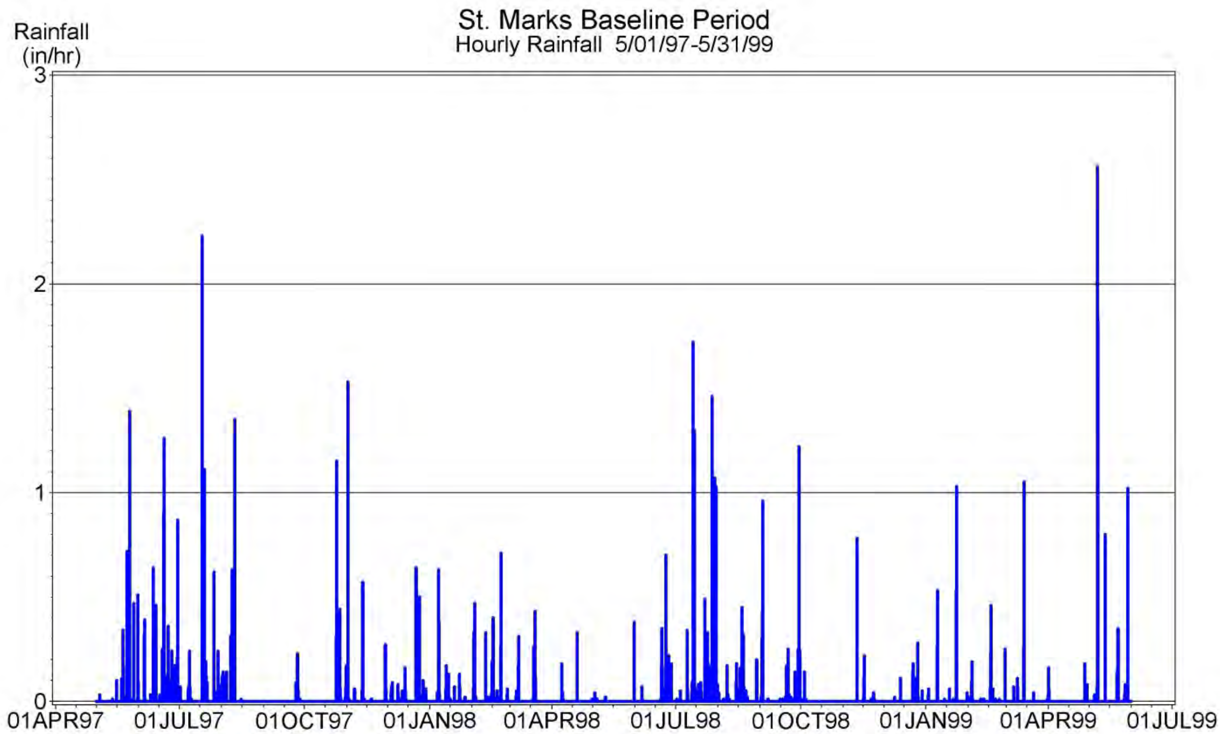

Figure 5. Hourly rainfall from Tallahassee Regional Airport.

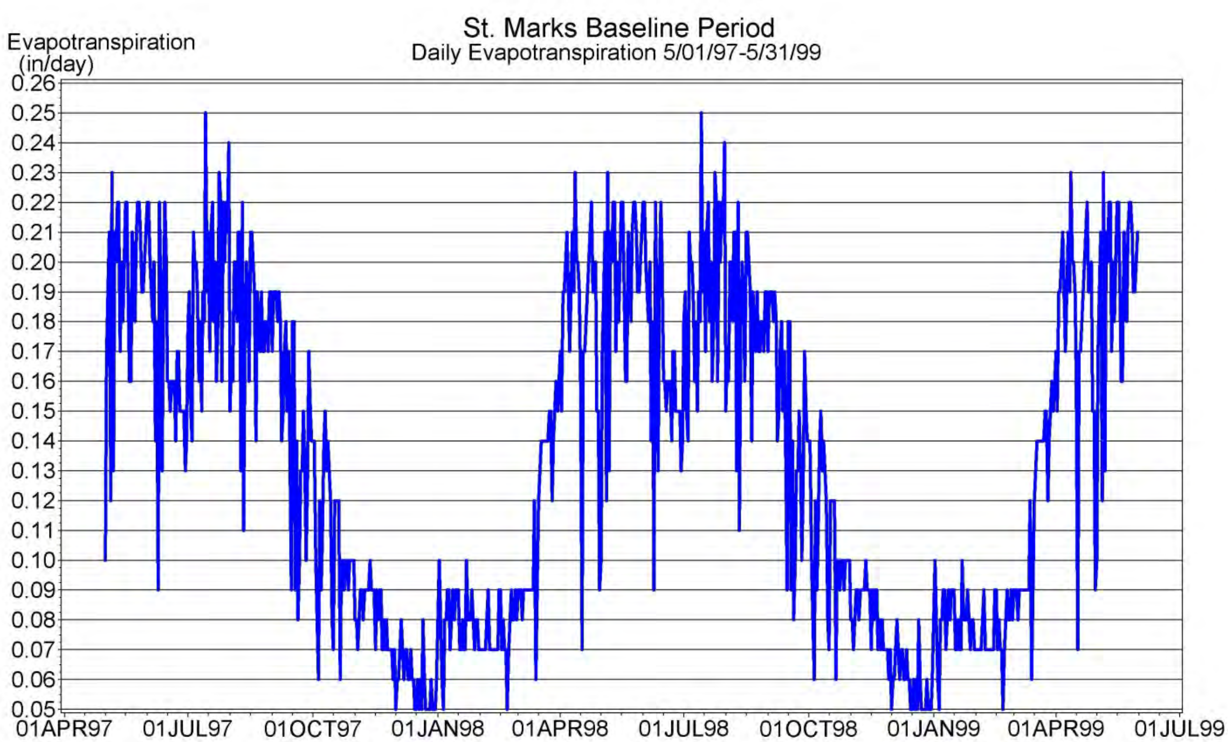

Figure 6. Daily evapotranspiration from Ocklawaha IFAS site.

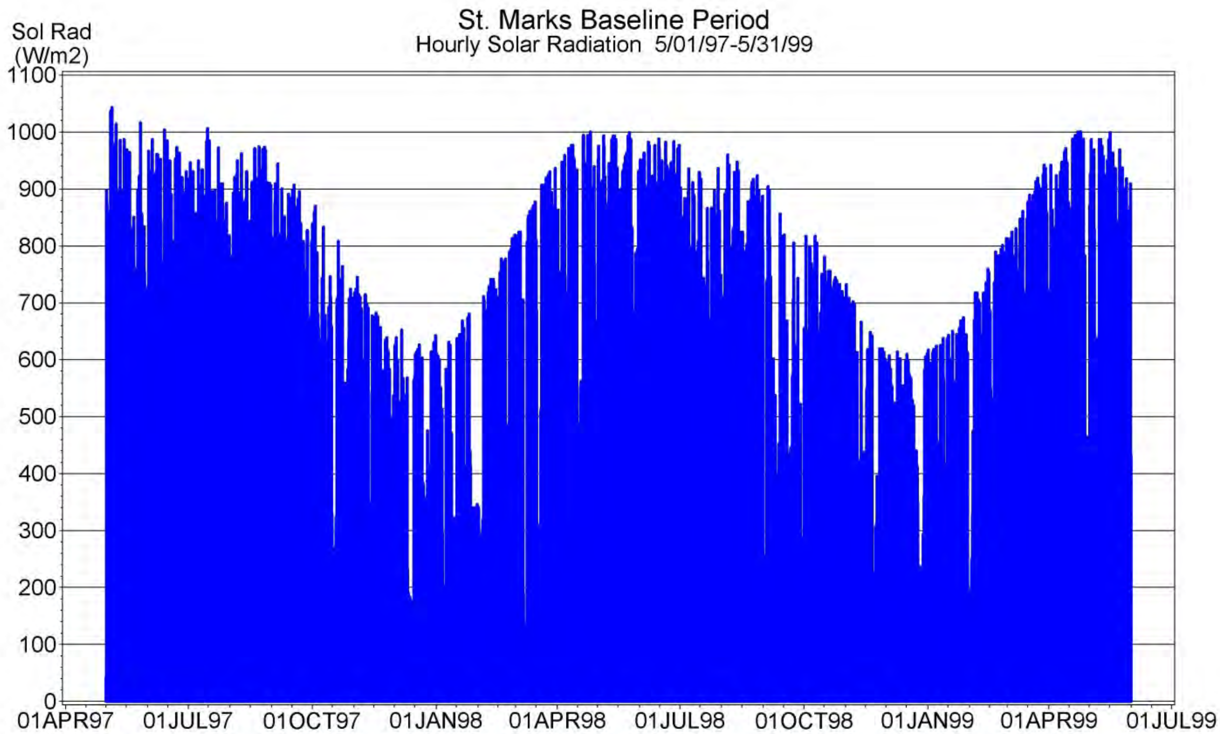

Figure 7. Hourly solar radiation from Tallahassee Regional Airport.

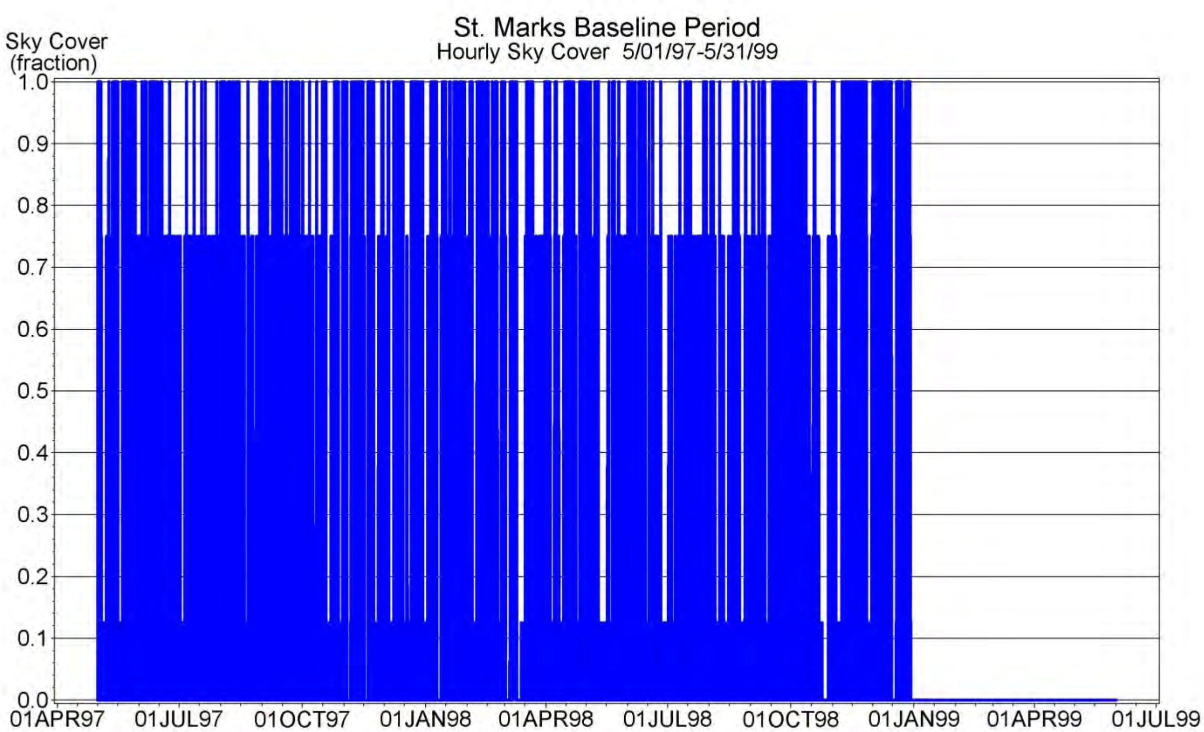

Figure 8. Hourly sky cover from Tallahassee Regional Airport.

- Winds (model input file WSER.INP): Hourly wind speed and direction are from the NOAA National Data Buoy Center (NDBC) Keaton Beach site. This is not the same site as used for the model calibration, which utilized data from the University of South Florida COMPS Shell Point site just west (~ 6 miles) of the mouth of the St. Marks River. However, the data record from the Shell Point site did not extend to the baseline period, so the next closest available data monitoring site (~40 miles from the mouth of the river) was used. Time series plots of the wind data from the Keaton Beach site are provided in Figures 9 and 10.

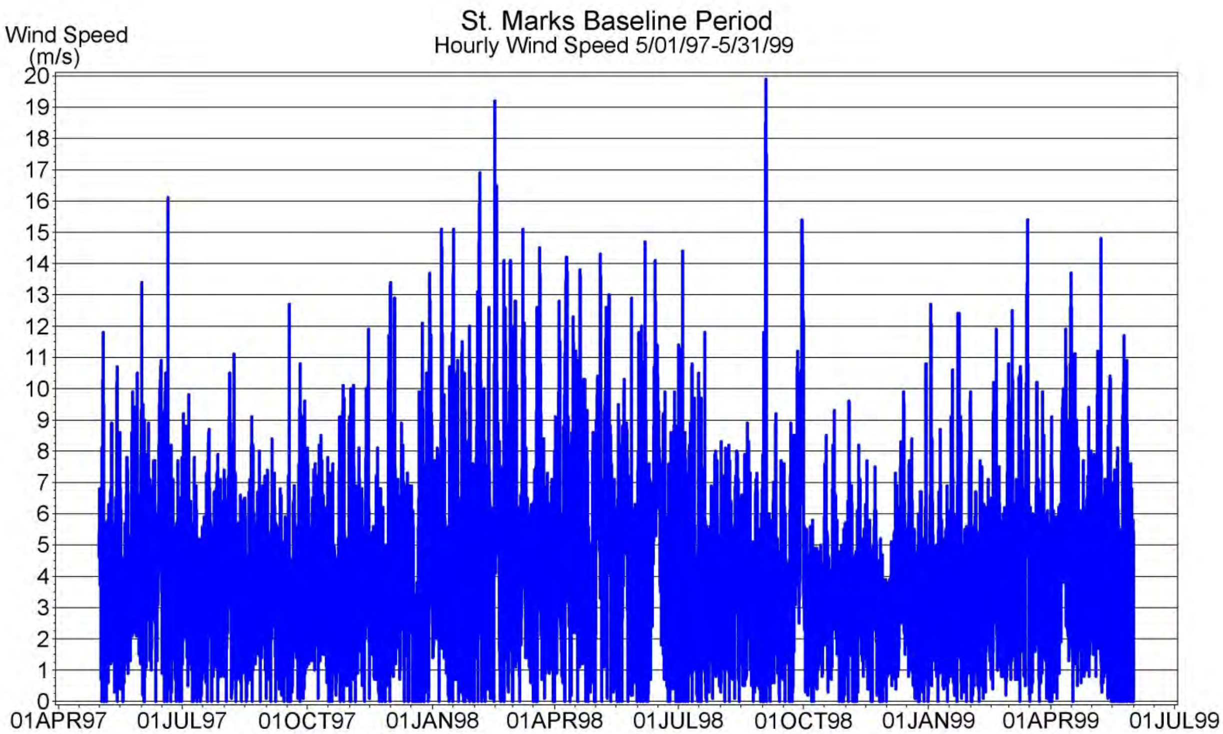

Figure 9. Hourly wind speed from Keaton Beach site.

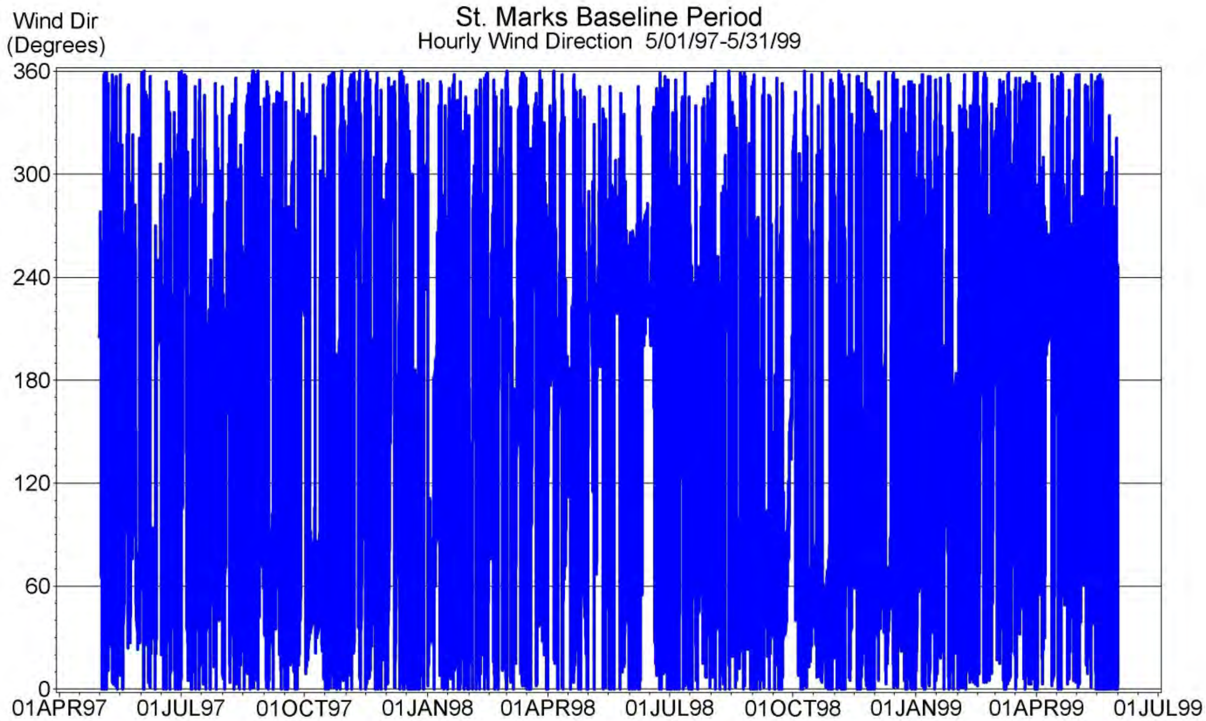

Figure 10. Hourly wind direction from Keaton Beach site.

- Offshore water surface elevations (model input file PSER.INP): The model grid system for the St. Marks and Wakulla model is provided in Figure 11a-c. The offshore boundary of the model is approximately 3 km away from the mouth of the river. No observed data exist to provide boundary conditions along the offshore boundary. Offshore boundary water surface elevations were based on output from the previously developed Gulf Coast Shelf Model (GCSM), a hydrodynamic model of the northeastern Gulf of Mexico (Janicki Environmental, 2007). The GCSM was developed under contract with the Southwest Florida Water Management District (SWFWMD) and with the Suwannee River Water Management District (SRWMD) contributing funding, and provides offshore boundary conditions, including water surface elevations, for the baseline period (5/01/97-5/31/99) based on output from previously completed model applications. The GCSM grid system is provided in Figure 12. The modeled water surface elevation conditions from the GCSM grid cell corresponding to the offshore boundary of the St. Marks and Wakulla model were used as the offshore water surface boundary conditions. The St. Marks and Wakulla model offshore water surface elevations boundary conditions are provided as a time series plot in Figure 13.

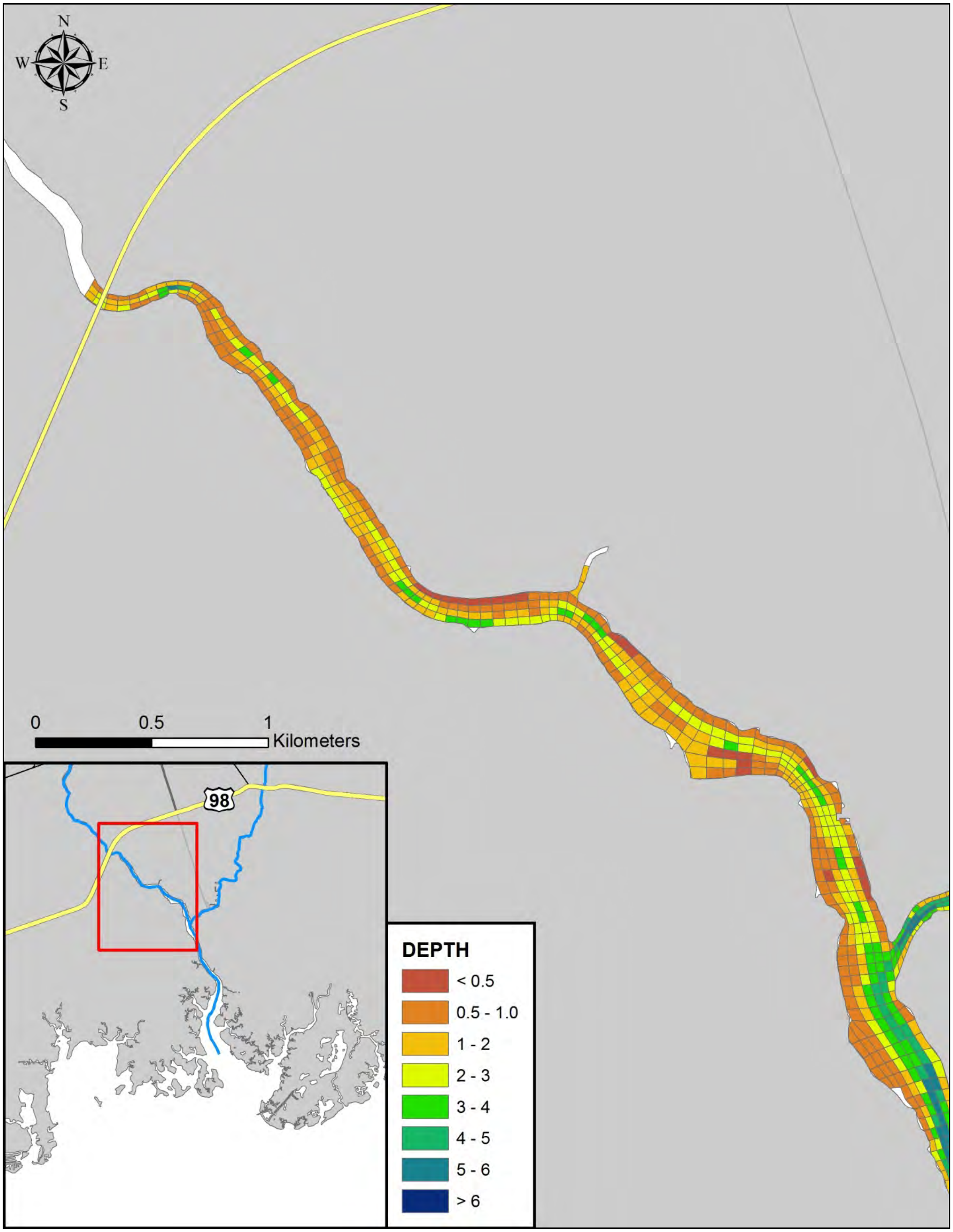

Figure 11a. Model grid and bathymetry for the Wakulla River portion of the model domain. Vertical reference is NAVD88, vertical (depth) units are meters.

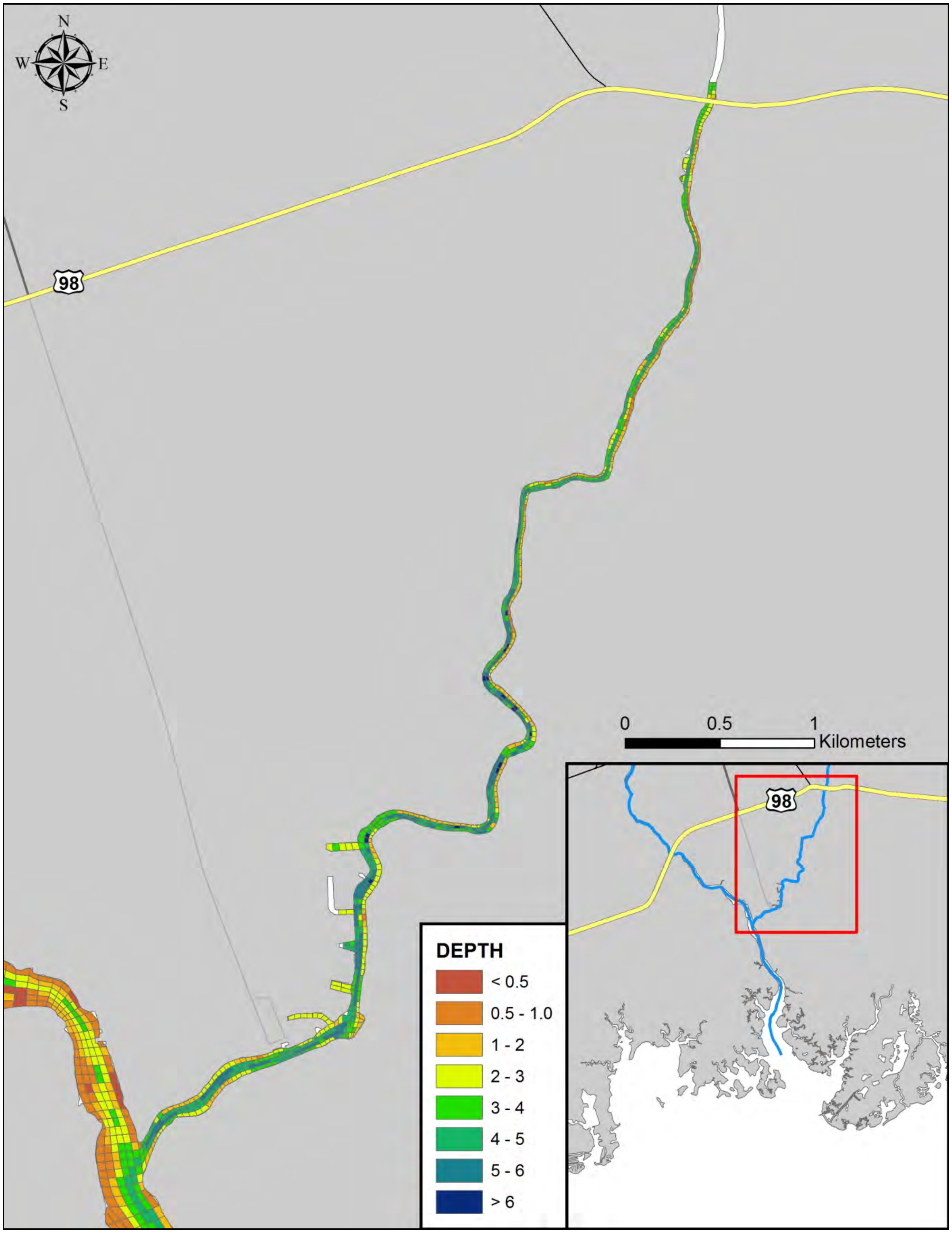

Figure 11b. Model grid and bathymetry for the St. Marks River upstream of the confluence within the model domain. Vertical reference is NAVD88, vertical (depth) units are meters.

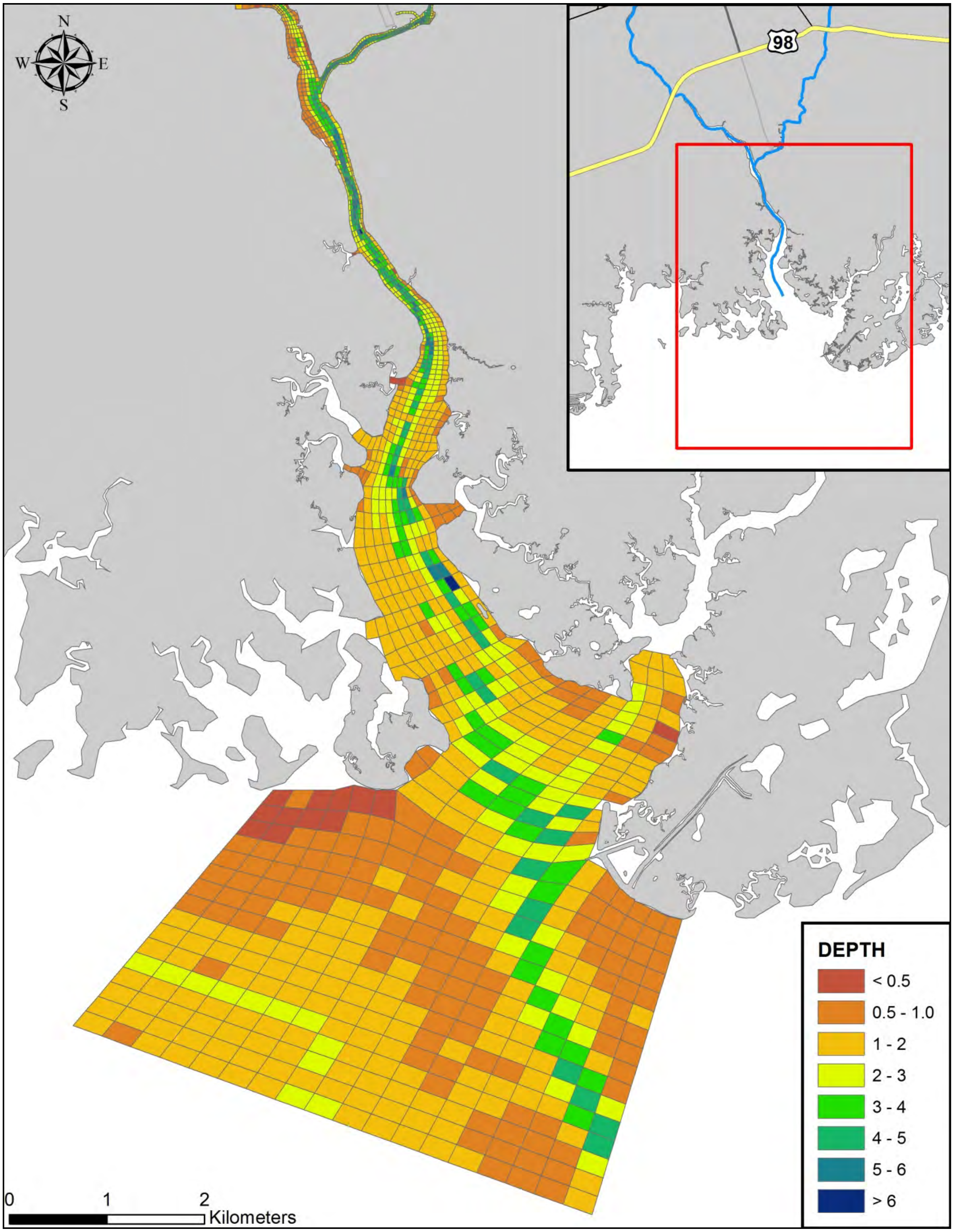

Figure 11c. Model grid and bathymetry for the St. Marks River from the confluence downstream to the offshore boundary of the model domain. Vertical reference is NAVD88, vertical (depth) units are meters.

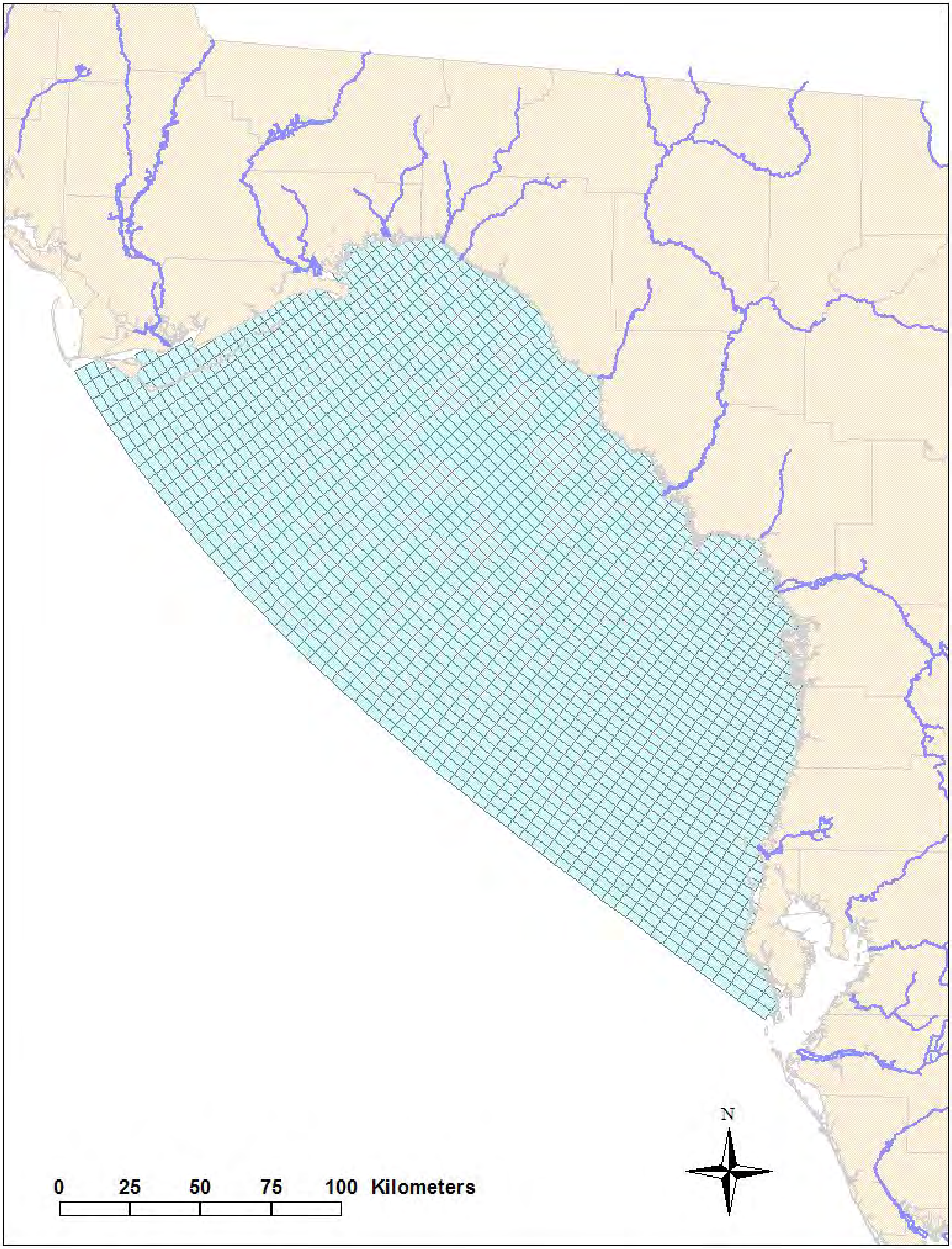

Figure 12. Model domain for the large-scale Gulf Coast Shelf Model (from Janicki Environmental, 2007).

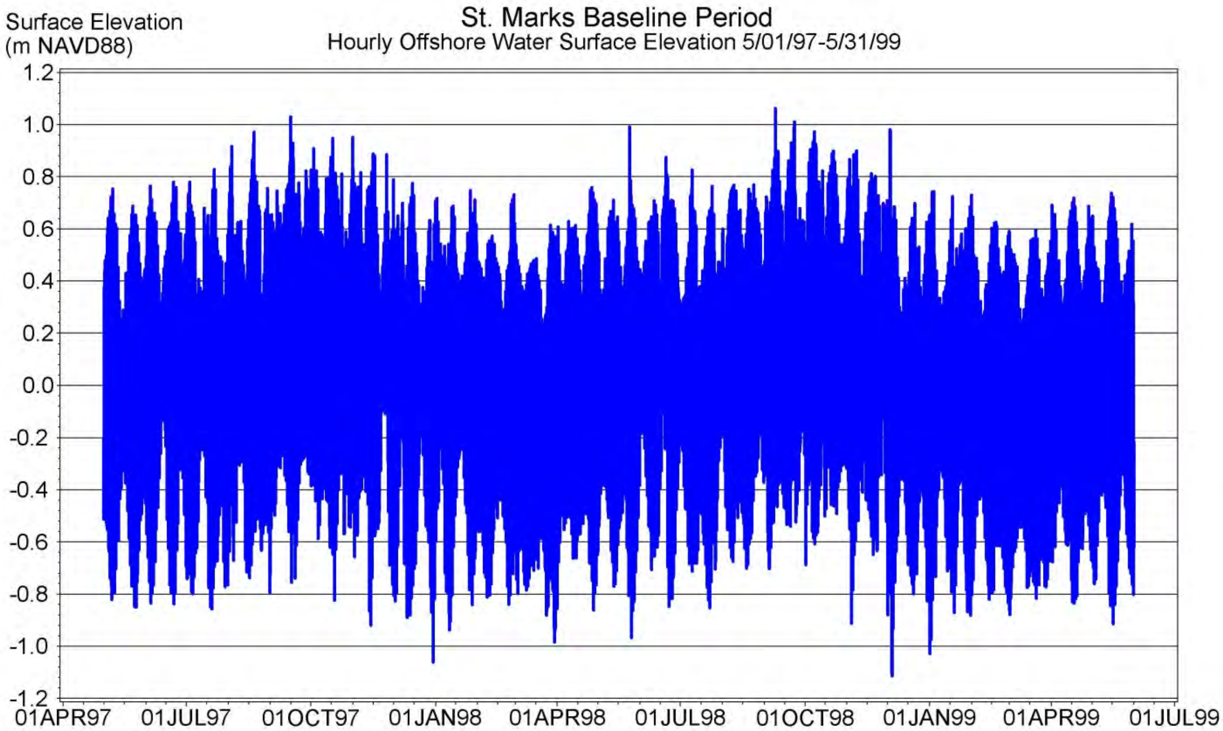

Figure 13. Hourly water surface elevation applied to offshore boundary, from GCSM (Janicki Environmental, 2007).

- Offshore and upstream salinity and temperature (model input files SSER.INP and TSER.INP): The offshore boundary conditions for salinity and temperature were obtained from output from the GCSM (described above) for the baseline period. Time series plots of the offshore boundary salinity and temperature are provided in Figures 14 and 15, respectively. Upstream salinity boundary conditions, input to the upstream model cells in the St. Marks River and Wakulla River, were set to 0 ppt, a close approximation to the very low values measured there during District monitoring, when observed salinity in the upstream St. Marks River was typically less than 0.2 ppt and observed salinity in the upstream Wakulla River was typically less than 0.3 ppt (Janicki Environmental, 2017; 2018a). Upstream water temperature boundary conditions input to the St. Marks River upstream model cells was set as equivalent to the air temperature over the baseline period as reported at the Tallahassee Regional Airport (Figure 2). This assumption is based on the relatively rapid (within a day or so) typical response of stream water temperature to atmospheric conditions, although the actual daily variations in water temperatures are not as rapid as those in air temperature. However, this assumption provides a reasonable temperature record for the freshwater inflows at the upstream St. Marks River, and is consistent between scenarios, so that this assumption does not play a role in differences found in WRV metrics between scenarios. Upstream water temperature boundary conditions input to the Wakulla River cells were set to a constant 20.5 °C, based on the data collected by the District from the continuous recorder monitoring at the US98 bridge crossing of the river.

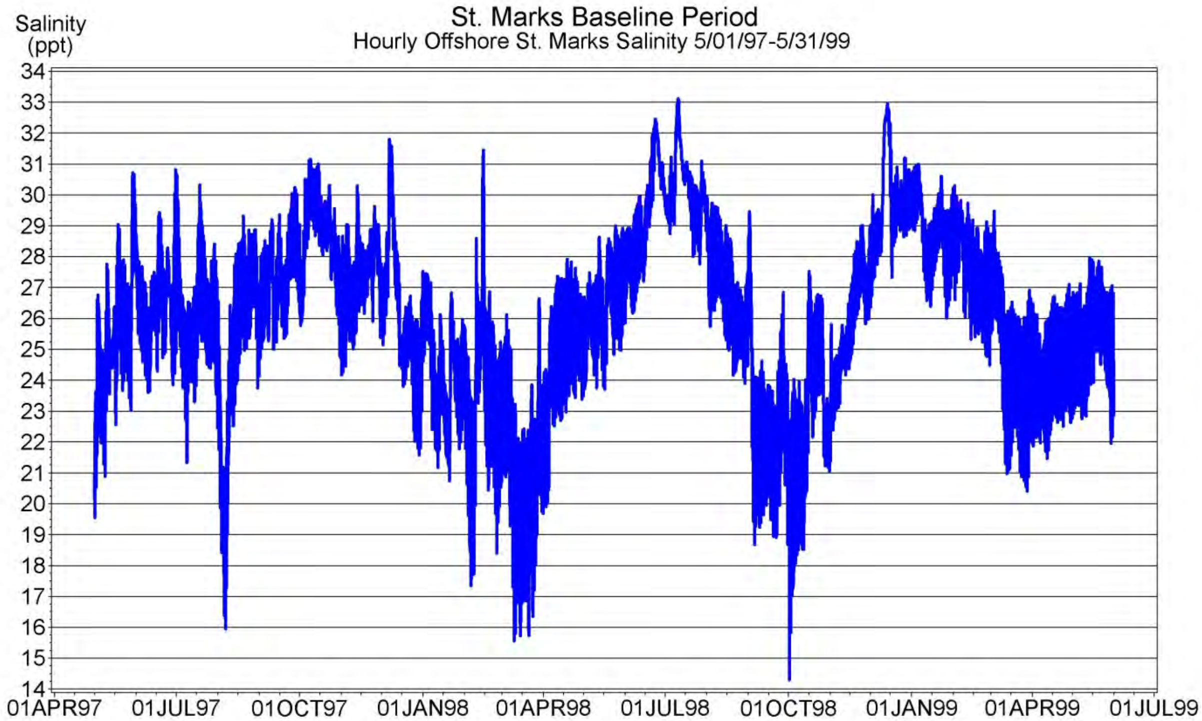

Figure 14. Hourly salinity applied to offshore boundary, from GCSM (Janicki Environmental, 2007).

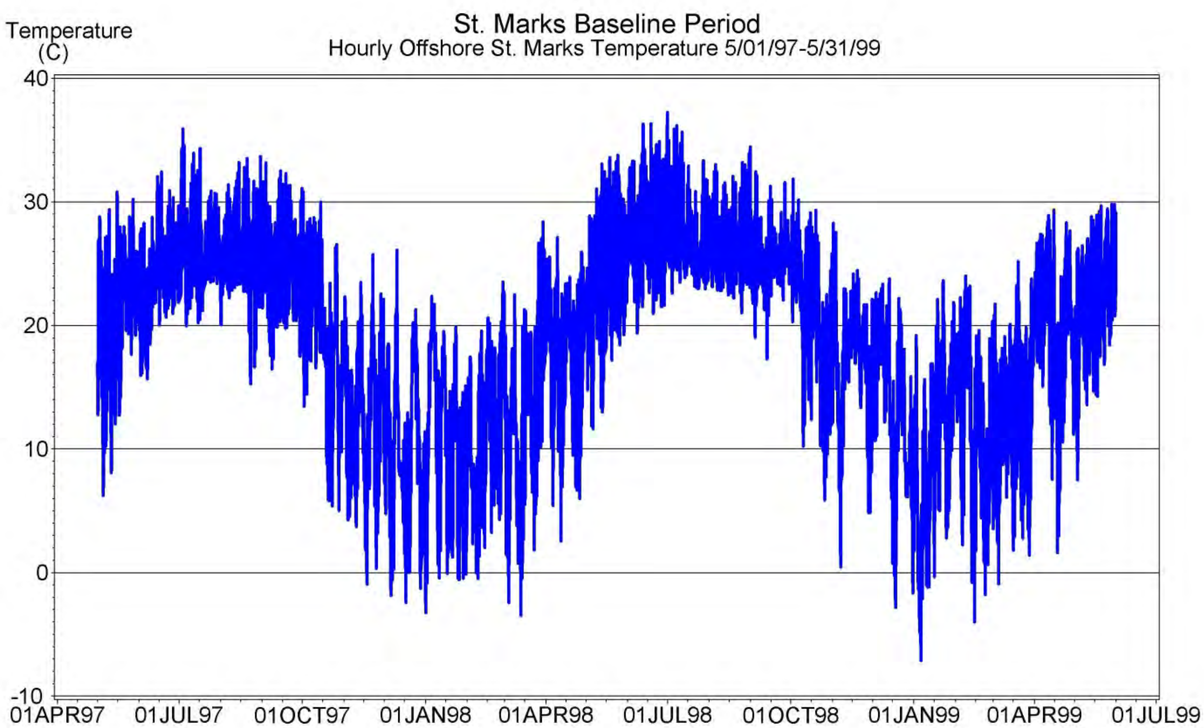

Figure 15. Hourly temperature applied to offshore boundary, from GCSM (Janicki Environmental, 2007).

- Initial conditions salinity and temperature (model input files SALT.INP and TEMP.INP): Initial conditions for salinity and water temperature are set to those used in the calibrated model, which were based on continuous recorder data from the river system for May 11, 2017, with groups of grid cells assigned to each continuous recorder, as indicated in Figures 16 and 17.

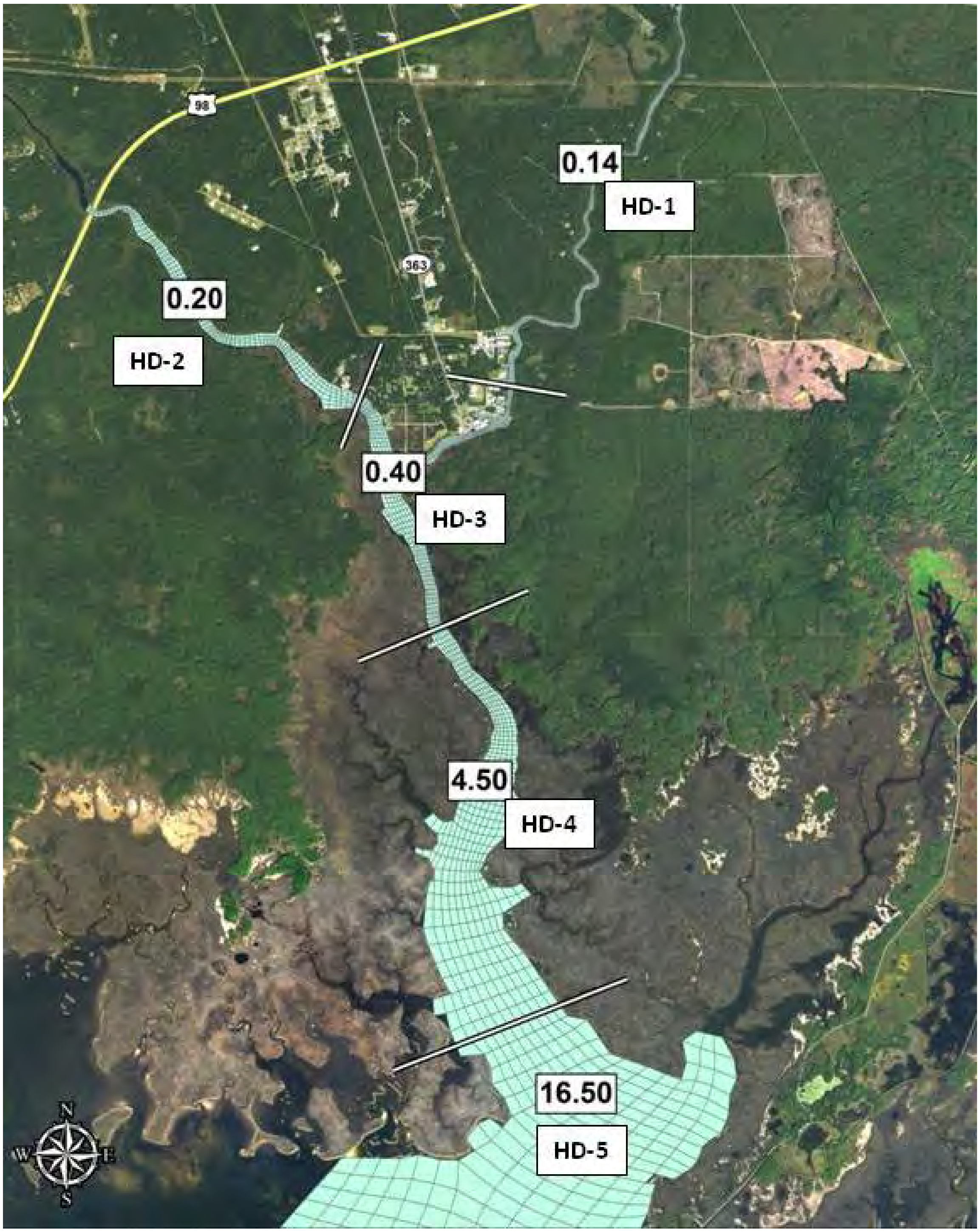

Figure 16. Initial condition salinity developed from continuous recorders (HD-*).

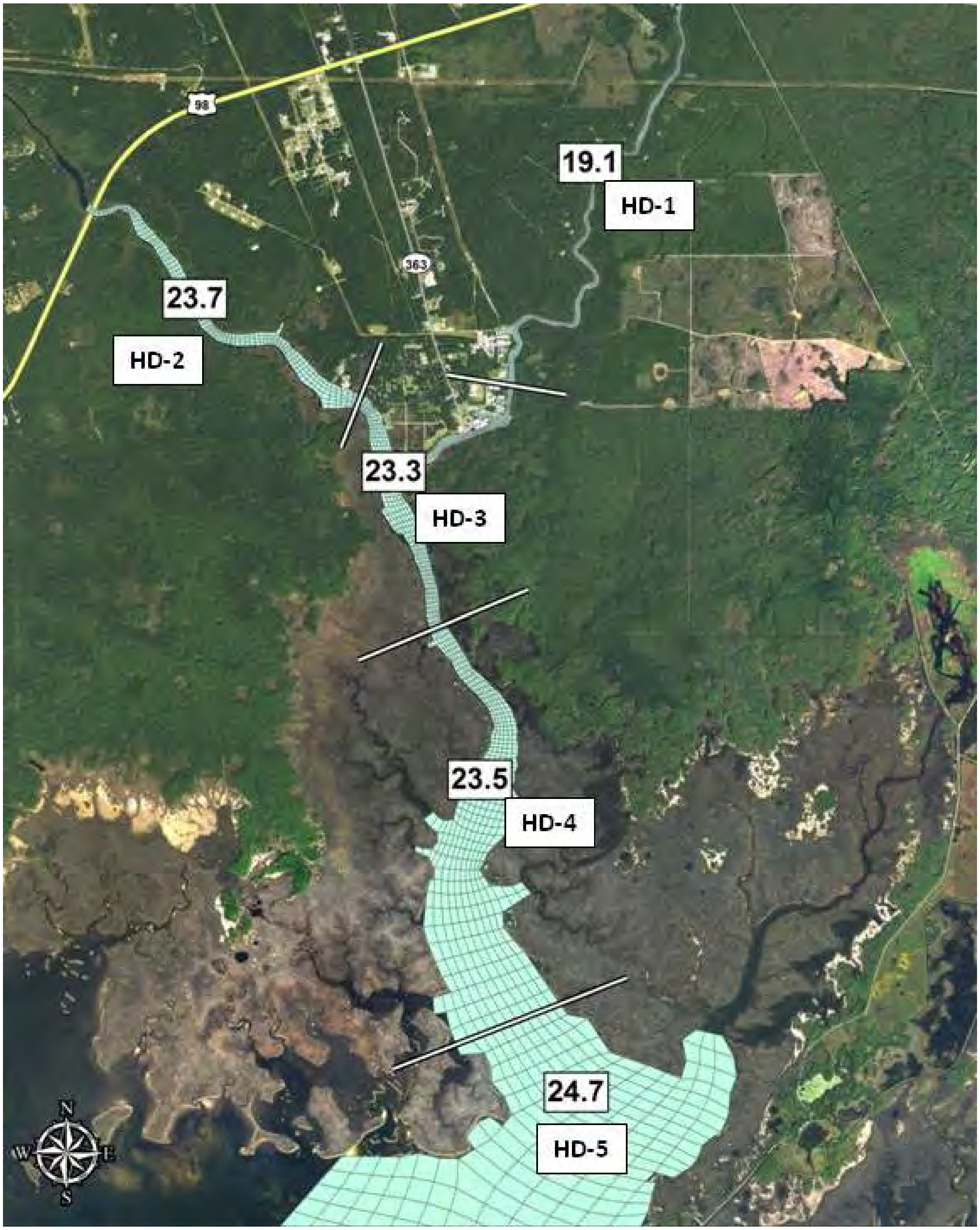

Figure 17. Initial condition water temperature developed from continuous recorders (HD-*).

- Freshwater inflows (model input file QSER.INP): Freshwater inflows at the upstream-most grid cells in each river were based on gaged flows from the St. Marks River near Newport, FL and the Wakulla River near Crawfordville, FL USGS gages (02326900 and 02327022, respectively, locations shown in Figure 1). The time series plot of the daily freshwater inflows to the upstream St. Marks River grid cells is provided in Figure 18. To account for inflows from the ungaged watershed of the St. Marks River between the USGS gage near Newport and the upstream cell of the model domain, the gaged flow was increased by a factor of 1.28865. This factor was estimated as part of the HEC-RAS work completed for this minimum flow evaluation and is based on estimated lateral ungaged inflows of 127 cfs when corresponding Newport gage flow was 440 cfs on August 25, 2017 (Applied Technology and Management, 2017). The time series plot of the daily freshwater inflows to the upstream Wakulla River grid cells is provided in Figure 19. These flow data were obtained directly from District staff as being the most reliable flow estimate based on the USGS gaged data at the Wakulla River near Crawfordville, FL gage (02327022).

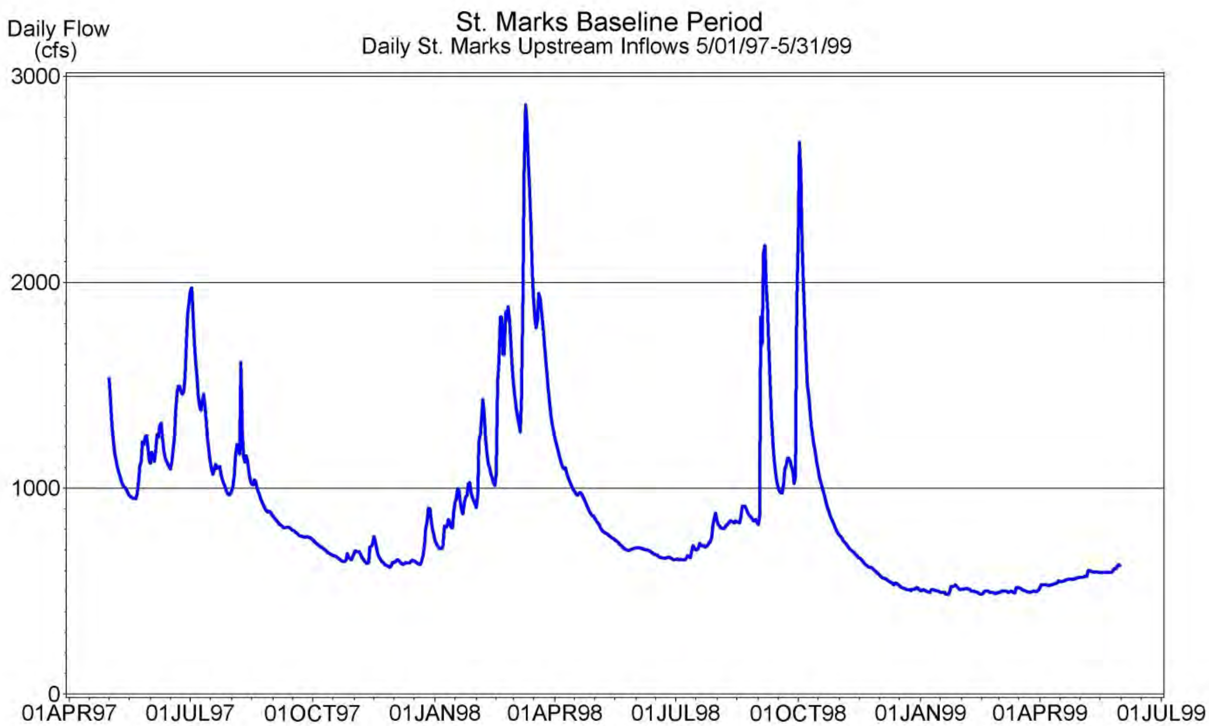

Figure 18. Inflows to model domain from upstream St. Marks River (based on USGS Station 02326900, St. Marks River near Newport, FL, see text).

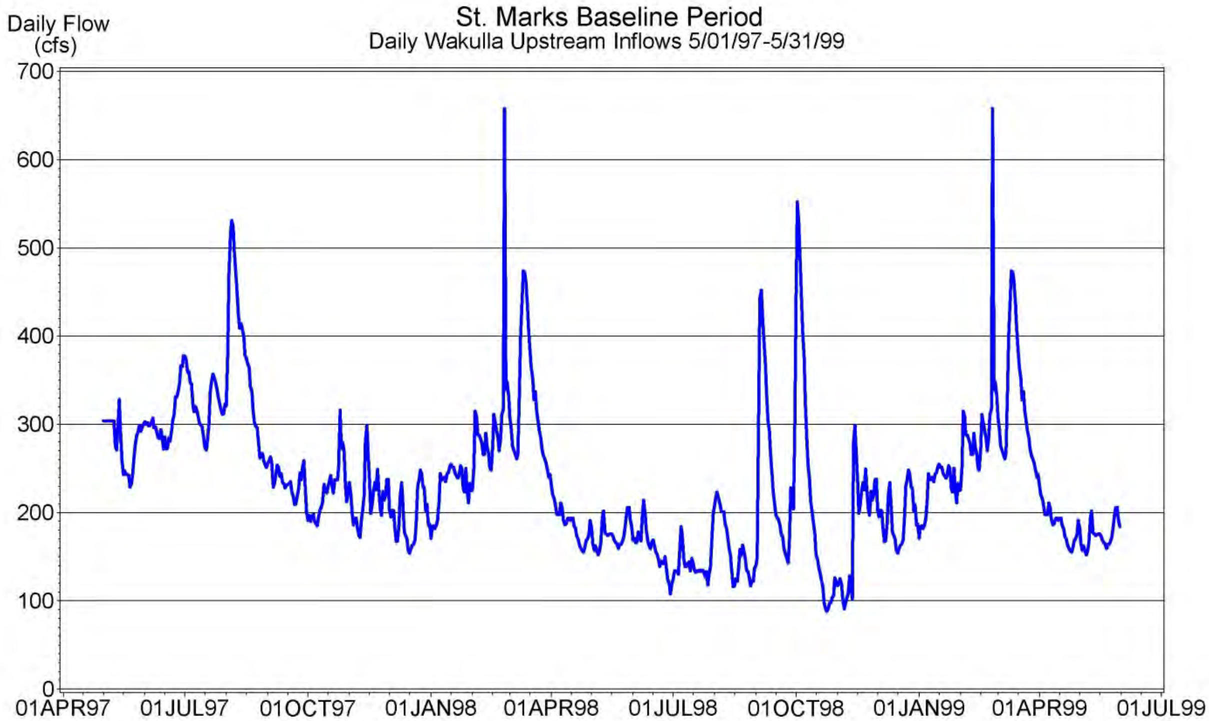

Figure 19. Inflows to model domain from upstream Wakulla River (USGS Station 02327022, Wakulla River near Crawfordville, FL).

3 Descriptions of Spring Flow Reduction and Sea Level Rise Scenarios for Minimum Flow Evaluation

Comparisons of the Estuarine Resources WRV metrics resulting from the baseline scenario, a spring flow reduction scenario, and a sea level rise scenario were used in the evaluation of minimum flows for the River Rise. The metrics associated with the Estuarine Resources WRV were volume, bottom surface area, and shoreline length of waters less than 0.5 ppt, 1 ppt, 2 ppt, 3 ppt, and 4 ppt salinity within the St. Marks River Rise spring run, which extends from the confluence of the Wakulla and St. Marks rivers upstream to the St. Marks River Rise. The hydrodynamic model domain corresponding to this area, within which any changes in salinity metrics resulting from changes in freshwater inflows are expected to occur, is from the confluence upstream to the US98 crossing of the St. Marks River, the upstream extent of the model grid system.

Once the baseline scenario was completed, an initial spring flow reduction scenario was selected and implemented, with the River Rise spring flow reduction set at 30%. Additionally, a scenario accounting for sea level rise predicted by 2038 (20 years in the future) was implemented, and the results compared to the baseline run. The modified inputs for each of these scenarios are described below.

3.1 River Rise Spring Flow Reduction

Minimum flows and minimum water levels (MFLs) are defined as the limit beyond which further water withdrawals would cause significant harm to the water resources or the ecology of the area. Although significant harm is not specifically defined in statute, a maximum 15% reduction in WRV metrics has been repeatedly implemented as the protection standard for multiple MFLs throughout Florida, accepted by more than a dozen MFL peer review panels, and is used in this assessment. An initial River Rise spring flow reduction of 30% was selected, with the intent that additional flow reduction scenarios would be performed as needed to determine minimum flows.

Flow emerging from the River Rise is a combination of spring flow and a smaller surface water contribution from the upper St. Marks River. The upper St. Marks River flows into a swallet at Natural Bridge where it reemerges approximately 0.6 miles south at the River Rise. Flow at the River Rise has increased considerably from that entering the swallet due to additional spring flow. To develop a River Rise flow record (i.e. spring flow) for the baseline period (5/01/97-5/31/99) to use as input to the upstream end of the model domain in the St. Marks River, the gaged flow at USGS 02326900, St. Marks River near Newport, FL was deconstructed into flow at the gage entering from upstream of the swallet above the spring, and flow at the gage due to the River Rise spring flow. The River Rise spring flow for the baseline period (5/01/97-5/31/99) developed by Janicki Environmental (2018b), a daily frequency flow record, was then reduced by 30%. This reduced River Rise spring flow was then added to the flow entering the swallet. The swallet inflows upstream of the Rise were calculated by subtracting the full River Rise spring flow from the gaged flow at the Newport gage (Janicki Environmental, 2018b). As in the baseline scenario, the additional inflows downstream of the Newport gage were accounted for by adding an additional 28.9% of the total observed Newport gage flow (as described above based on the HEC-RAS modeling; Applied Technology and Management, 2017) to the sum of the reduced spring flow record and the upstream inflow record. The resultant inflow to the upstream St. Marks River portion of the model domain is provided in Figure 20, with the unimpacted (baseline) inflow provided for comparison.

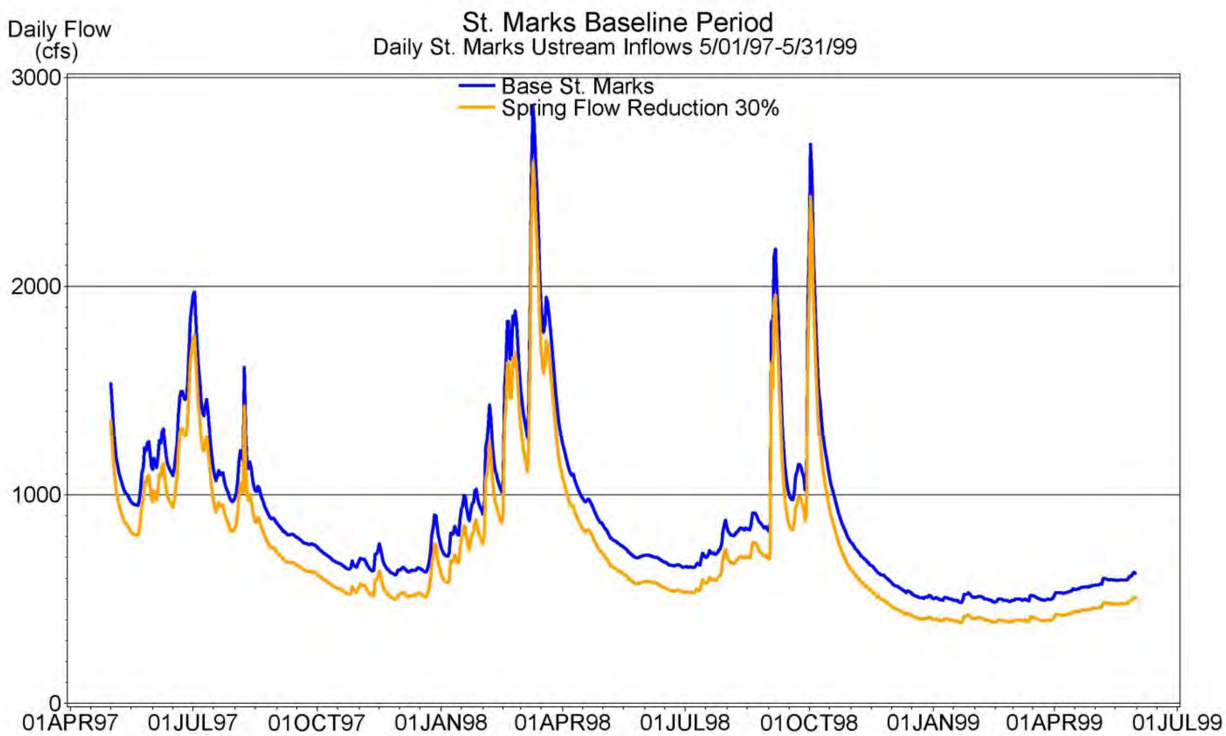

Figure 20. Inflows to model domain from upstream St. Marks River for the 30% spring flow reduction scenario (orange) and the baseline St. Marks River inflows (blue).

All other inputs to the 30% spring flow reduction run were as provided above for the baseline scenario.

3.2 Sea Level Rise

The sea level rise scenario was implemented by increasing the baseline offshore water surface elevation boundary condition time series (provided in Figure 13) to account for predicted increases in sea level by 2038. The predicted increase was derived from U.S. Army Corps of Engineers (2018) projections for the median sea level rise at Apalachicola, FL (2.64 inches) and Cedar Key, FL (3.0 inches), with the average of these taken to arrive at a mean sea level rise of 2.82 inches by 2038 for the mouth of the St. Marks River. This increase in the offshore water surface elevation boundary condition was applied over the entire baseline model period (5/01/97-5/31/99), and the resulting model output compared to the baseline scenario output by calculating and comparing the WRV metrics.

4 Results

The 30% spring flow reduction scenario was compared to the baseline scenario to ascertain the responsiveness of the WRV metrics to this relatively large spring flow reduction. Recall the WRV metrics of interest were the volume, bottom area, and shoreline length of waters less than 0.5 ppt, 1 ppt, 2 ppt, 3 ppt, and 4 ppt within the St. Marks River Rise spring run (from the confluence to the US98 bridge crossing of the St. Marks River for the hydrodynamic model).

For this WRV metric comparison, two different analyses were completed. First, the average daily volumes, bottom areas, and shoreline lengths of each salinity envelope (≤0.5 ppt, ≤1 ppt, ≤2 ppt, ≤3 ppt, and ≤4 ppt) were calculated over the 5/01/97-5/31/99 period for each scenario. Then, both the median and mean metric values for each salinity envelope over the full period were calculated.

Table 1 below provides these results comparing the baseline scenario and the 30% spring flow reduction run for the spring run portion of the model domain (that area from the confluence upstream to the US98 bridge crossing of the St. Marks River), using the median of the daily average values for comparison. Table 2 similarly shows comparison results, based on the average (not the meadian) of the daily average values. As shown in both Tables 1 and 2, the reduction in WRV metrics within the spring run (confluence upstream to the US98 Bridge) for a 30% spring flow reduction never reaches 15%, indicating that estuarine resource metrics are relatively insensitive to reductions in flow from the River Rise.

It should be noted that for the certain metrics and certain salinity zones, there are no differences between the baseline and the 30% spring flow reduction scenarios within the spring run (as in Table 1, shoreline length for the ≤ 3 ppt salinity zone). This is because the evaluations reported in Tables 1 and 2 encompass the spring run, between the confluence and the US98 Bridge crossing of the St. Marks River. When considering the entire river system, including the Wakulla River, and extending to the mouth of the St. Marks River, it is seen that the 30% River Rise spring flow reduction scenario also results in reductions in all metrics across all salinity zones evaluated (Tables 3 and 4), although still not to the 15% metric reduction level.

To understand better how the reductions in the River Rise spring flow impact the salinity distribution, maps depicting the spatial distribution of surface and bottom salinity for both the baseline and the 30% spring flow reduction scenarios are provided. Figures 21 and 22 show the salinity distributions for bottom salinity during a relatively low flow period (25th percentile spring flow) and a relatively high flow period (75th percentile spring flows), for both scenarios. As can be seen in these two figures, obvious differences exist between the two scenarios for a given condition, and these differences occur not only in the spring run of the St. Marks River but also extend into the Wakulla River and downstream of the confluence.

Table 1. Comparison of WRV metrics for median volume, bottom area, and shoreline length in spring run for baseline (Base) and River Rise spring flow reduction (30%) scenarios.

Scenario	Volume ≤ 0.5 ppt (m^3)	Percent Reduction	Bottom Area ≤ 0.5 ppt (m^2)	Percent Reduction	Shoreline ≤ 0.5 ppt (m)	Percent Reduction
Base	1,388,070	10.2	357,554	11.5	16,970	6.1
30% Reduction	1,245,866		316,408		15,930	
Scenario	**Volume ≤ 1 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 1 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 1 ppt (m)**	**Percent Reduction**
Base	1,476,702	7.8	390,939	11.6	17,112	0.3
30% Reduction	1,361,363		345,420		17,065	
Scenario	**Volume ≤ 2 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 2 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 2 ppt (m)**	**Percent Reduction**
Base	1,530,601	2.8	428,442	9.4	17,112	0.0
30% Reduction	1,488,267		388,100		17,112	
Scenario	**Volume ≤ 3 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 3 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 3 ppt (m)**	**Percent Reduction**
Base	1,550,553	1.7	435,664	3.5	17,112	0.0
30% Reduction	1,523,896		420,438		17,112	
Scenario	**Volume ≤ 4 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 4 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 4 ppt (m)**	**Percent Reduction**
Base	1,555,486	0.8	435,664	0.0	17,112	0.0
30% Reduction	1,542,850		435,664		17,112	

Table 2. Comparison of WRV metrics for average volume, bottom area, and shoreline length in the spring run for baseline (Base) and River Rise spring flow reduction (30%) scenarios.

Scenario	Volume ≤ 0.5 ppt (m^3)	Percent Reduction	Bottom Area ≤ 0.5 ppt (m^2)	Percent Reduction	Shoreline ≤ 0.5 ppt (m)	Percent Reduction
Base	1,304,647	8.1	346,563	7.8	15,652	5.8
30% Reduction	1,199,517		319,487		14,742	
Scenario	**Volume ≤ 1 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 1 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 1 ppt (m)**	**Percent Reduction**
Base	1,368,708	6.8	360,966	7.1	16,290	4.3
30% Reduction	1,257,759		335,392		15,588	
Scenario	**Volume ≤ 2 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 2 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 2 ppt (m)**	**Percent Reduction**
Base	1,434,916	5.1	378,380	6.0	16,766	2.5
30% Reduction	1,361,278		355,828		16,342	
Scenario	**Volume ≤ 3 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 3 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 3 ppt (m)**	**Percent Reduction**
Base	1,471,102	4.0	390,003	5.0	16,947	1.6
30% Reduction	1,411,973		370,338		16,682	
Scenario	**Volume ≤ 4 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 4 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 4 ppt (m)**	**Percent Reduction**
Base	1,493,855	3.2	397,612	4.1	17,055	1.1
30% Reduction	1,446,437		381,313		16,875	

Table 3. Comparison of WRV metrics for median volume, bottom area, and shoreline length over river system upstream of river mouth for baseline (Base) and River Rise spring flow reduction (30%) scenarios.

Scenario	Volume ≤ 0.5 ppt (m^3)	Percent Reduction	Bottom Area ≤ 0.5 ppt (m^2)	Percent Reduction	Shoreline ≤ 0.5 ppt (m)	Percent Reduction
Base	2,246,095	12.8	913,636	13.4	25,925	7.0
30% Reduction	1,953,011		791,449		24,111	
Scenario	**Volume ≤ 1 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 1 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 1 ppt (m)**	**Percent Reduction**
Base	2,585,331	12.0	1,022,312	11.4	28,237	5.3
30% Reduction	2,275,239		905,882		26,736	
Scenario	**Volume ≤ 2 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 2 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 2 ppt (m)**	**Percent Reduction**
Base	3,097,877	10.2	1,180,532	9.0	31,400	4.1
30% Reduction	2,781,257		1,074,378		30,101	
Scenario	**Volume ≤ 3 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 3 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 3 ppt (m)**	**Percent Reduction**
Base	3,517,358	8.8	1,277,495	6.8	33,610	3.0
30% Reduction	3,206,367		1,190,207		32,591	
Scenario	**Volume ≤ 4 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 4 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 4 ppt (m)**	**Percent Reduction**
Base	3,923,130	8.9	1,351,300	5.2	34,926	2.4
30% Reduction	3,573,499		1,280,952		34,083	

Table 4. Comparison of WRV metrics for average volume, bottom area, and shoreline length over river system upstream of river mouth for baseline (Base) and River Rise spring flow reduction (30%) scenarios.

Scenario	Volume ≤ 0.5 ppt (m^3)	Percent Reduction	Bottom Area ≤ 0.5 ppt (m^2)	Percent Reduction	Shoreline ≤ 0.5 ppt (m)	Percent Reduction
Base	2,521,996	9.9	987,330	8.9	25,991	6.5
30% Reduction	2,271,716		899,417		24,308	
Scenario	**Volume ≤ 1 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 1 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 1 ppt (m)**	**Percent Reduction**
Base	2,893,652	9.9	1,105,376	9.0	28,388	5.7
30% Reduction	2,607,928		1,006,224		26,764	
Scenario	**Volume ≤ 2 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 2 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 2 ppt (m)**	**Percent Reduction**
Base	3,476,970	9.5	1,290,203	8.9	31,327	4.6
30% Reduction	3,146,764		1,175,554		29,872	
Scenario	**Volume ≤ 3 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 3 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 3 ppt (m)**	**Percent Reduction**
Base	3,975,647	9.0	1,448,236	8.6	33,338	3.9
30% Reduction	3,616,432		1,324,450		32,047	
Scenario	**Volume ≤ 4 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 4 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 4 ppt (m)**	**Percent Reduction**
Base	4,446,551	8.7	1,602,166	8.4	34,995	3.5
30% Reduction	4,060,264		1,467,698		33,767	

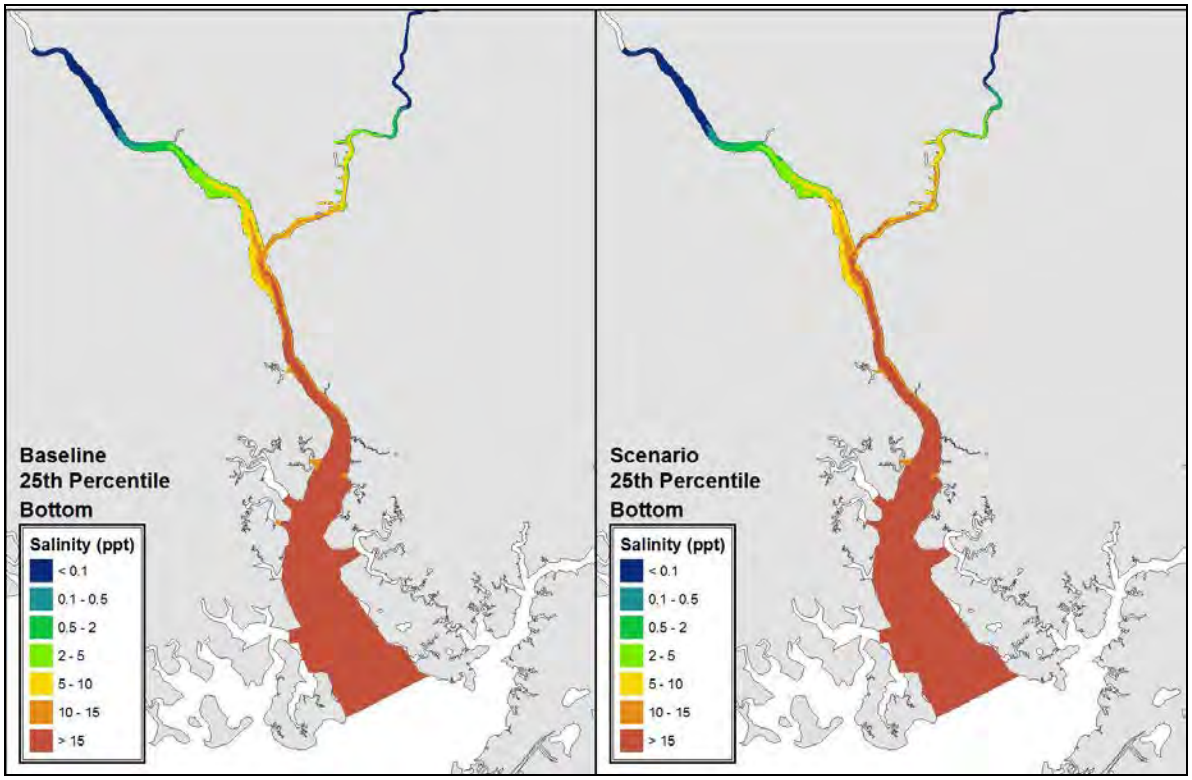

Figure 21. Bottom salinity distribution at 25th percentile River Rise spring flow for baseline (left) and 30% spring flow reduction (right) scenarios.

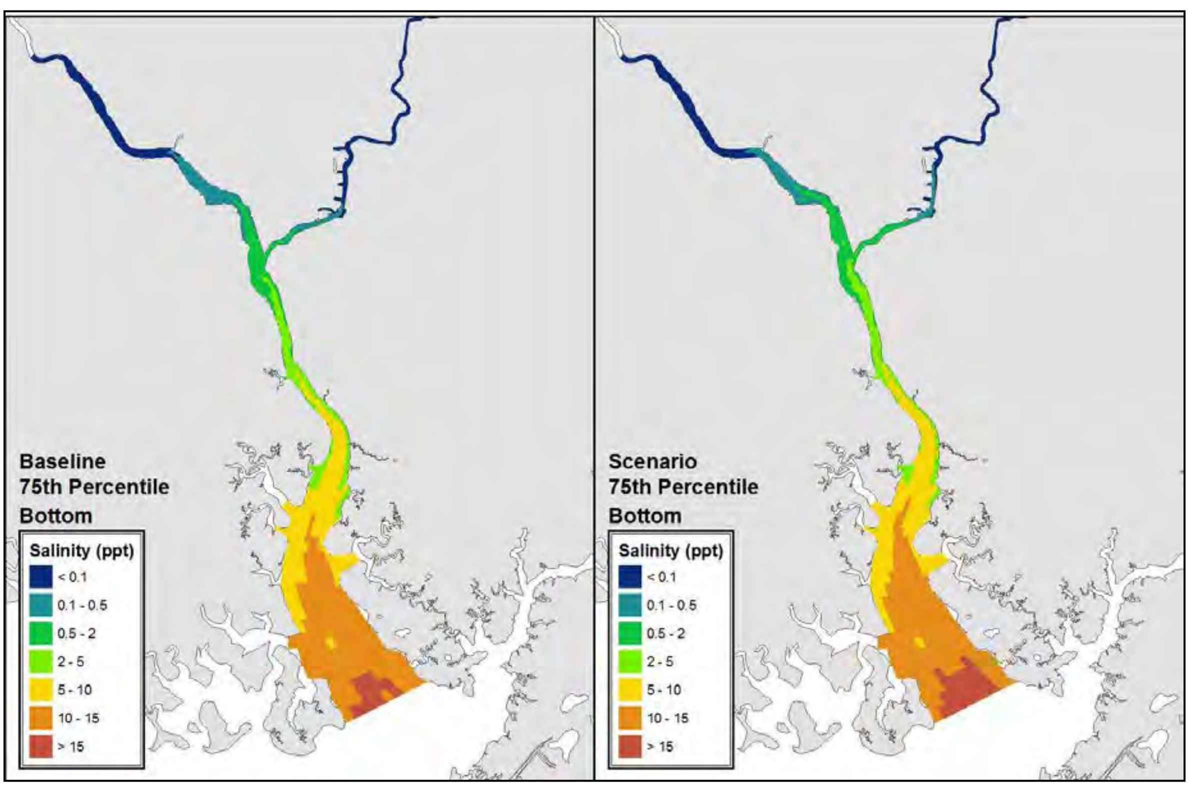

Figure 22. Bottom salinity distribution at 75th percentile River Rise spring flow for baseline (left) and 30% spring flow reduction (right) scenarios.

Tables 5 and 6 provide the results of comparison of the habitat metrics of the baseline scenario and the sea level rise scenario. Recall the sea level rise scenario incorporated a constant water boundary elevation increase of 2.82 inches over the baseline time period (5/01/97-5/31/99). Notice in Table 5 that for less than 4 ppt, the median volume actually increases slightly in the sea level rise scenario. This is likely the result of the higher offshore elevations leading to the river system increasing freshwater retention time. For sea level rise of this level over the next 20 years, this comparison indicates that the 15% habitat reduction threshold will not be threatened.

Table 5. Comparison of WRV metrics for median volume, bottom area, and shoreline length in spring run for baseline (Base) and sea level rise (SLR) scenarios.

Scenario	Volume ≤ 0.5 ppt (m^3)	Percent Reduction	Bottom Area ≤ 0.5 ppt (m^2)	Percent Reduction	Shoreline ≤ 0.5 ppt (m)	Percent Reduction
Base	1,388,070	9.7	357,554	12.7	16,970	6.6
SLR	1,254,022		312,036		15,853	
Scenario	**Volume ≤ 1 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 1 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 1 ppt (m)**	**Percent Reduction**
Base	1,476,702	6.9	390,939	13.7	17,112	0.5
SLR	1,374,908		337,393		17,032	
Scenario	**Volume ≤ 2 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 2 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 2 ppt (m)**	**Percent Reduction**
Base	1,530,601	2.3	428,442	11.4	17,112	0.0
SLR	1,495,879		379,755		17,112	
Scenario	**Volume ≤ 3 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 3 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 3 ppt (m)**	**Percent Reduction**
Base	1,550,553	0.1	435,664	6.3	17,112	0.0
SLR	1,548,415		408,230		17,112	
Scenario	**Volume ≤ 4 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 4 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 4 ppt (m)**	**Percent Reduction**
Base	1,555,486	-0.8	435,664	0.3	17,112	0.0
SLR	1,567,804		434,163		17,112	

Table 6. Comparison of WRV metrics for average volume, bottom area, and shoreline length in spring run for baseline (Base) and sea level rise (SLR) scenarios.

Scenario	Volume ≤ 0.5 ppt (m^3)	Percent Reduction	Bottom Area ≤ 0.5 ppt (m^2)	Percent Reduction	Shoreline ≤ 0.5 ppt (m)	Percent Reduction
Base	1,304,647	6.4	346,563	8.0	15,652	5.8
SLR	1,221,752		318,784		14,747	
Scenario	**Volume ≤ 1 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 1 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 1 ppt (m)**	**Percent Reduction**
Base	1,368,708	5.3	360,966	7.7	16,290	4.3
SLR	1,296,381		333,351		15,582	
Scenario	**Volume ≤ 2 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 2 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 2 ppt (m)**	**Percent Reduction**
Base	1,434,916	3.6	378,380	6.7	16,766	2.4
SLR	1,382,771		353,210		16,363	
Scenario	**Volume ≤ 3 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 3 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 3 ppt (m)**	**Percent Reduction**
Base	1,471,102	2.4	390,003	5.8	16,947	1.4
SLR	1,435,380		367,357		16,719	
Scenario	**Volume ≤ 4 ppt (m^3)**	**Percent Reduction**	**Bottom Area ≤ 4 ppt (m^2)**	**Percent Reduction**	**Shoreline ≤ 4 ppt (m)**	**Percent Reduction**
Base	1,493,855	1.5	397,612	4.9	17,055	0.9
SLR	1,471,163		378,248		16,900	

5 Conclusions

A baseline model scenario was developed and implemented for the period 5/01/97-5/31/99, when the River Rise spring flow distributions were very similar to those for the full period of record, as described in Janicki Environmental (2018b). A River Rise spring flow reduction scenario was implemented and evaluated along with a sea level rise scenario. Even with a 30% reduction in River Rise spring flow, no habitat metrics were reduced by 15% or more relative to the baseline conditions.

The results also indicated that changes in low-salinity habitat metrics within the spring run are not linear with respect to spring flow reductions. Overall, salinity habitat metrics within the spring run and river system are relatively insensitive to changes in spring flow from the River Rise. Because other WRV metrics, such as boating passage and floodplain inundation, are more sensitive to River Rise spring flow reductions, it was not necessary to evaluate the effect of larger spring flow reduction scenarios (e.g. 40% reduction, 50% reduction) on Estuarine Resources.

6 References

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