Memo

Date:	Wednesday, November 15, 2023
Project:	LIS-HWQMS
To:	DEP
From:	HDR
Subject:	RCA WY95 Water Quality Model Testing

1. Introduction

1.1. Background

The New York City Department of Environmental Protection (DEP) and United States Environmental Protection Agency (EPA) are funding the development of a coupled hydrodynamic/water quality model of Long Island Sound (LIS) to replace the existing System-wide Eutrophication Model (SWEM). SWEM used a combination of the Estuarine and Coastal Ocean Model (ECOM) for hydrodynamics and the Row-Column Advanced Ecological Systems Modeling Program (RCA) for water quality. The current project is using the Regional Ocean Modeling System (ROMS) hydrodynamic model coupled with the RCA water quality model for the updated LIS model (HDR, 2021). ROMS and RCA have previously been coupled and applied to the Chesapeake Bay (Testa et al., 2014).

This memorandum presents testing of the coupled ROMS-RCA water quality model simulating the SWEM validation time period of water year 1995 (WY95) (10/1/1994-9/30/1995) using the original SWEM inputs as much as possible. In addition, various adjustments to ROMS-RCA water quality model inputs were tested to determine how these adjustments could improve upon the existing SWEM model and to inform the preliminary calibration of the ROMS-RCA water quality model to calendar years 2005-2006 (CY05-06). The LIS Model Evaluation Group (MEG) strongly suggested that no effort should be made to calibrate the ROMS-RCA water quality model to the WY95 data. The work summarized in this memo follows that recommendation. It should be noted that ECOM and ROMS have different underlying model algorithms, so not all the ECOM inputs are compatible with the required ROMS inputs. This means that different hydrodynamic (transport) models are used as the starting point for application of the ECOM-RCA and ROMS-RCA water quality models. Moreover, this results in different RCA water quality model results even if all the other (non-transport related) water quality inputs are the same. Comparisons between ECOM-RCA and ROMS-RCA model results are presented in this memo. Although some effort was made to adjust ROMS-RCA water quality model inputs to reproduce ECOM-RCA results, an exact match between models was not possible due to differences in the model grids, hydrodynamic models, and upgrades that have occurred in RCA and SWEM over the last two decades (e.g., additions of a third algal group, reactive particulate organic carbon, and algal basal respiration).

In the past, a number of “hardwired” code features were added to SWEM ECOM and RCA. The hardwired code features (i.e., minimum air temperature in ECOM, modified vertical mixing in RCA, and enhanced organic matter deposition due to suspension feeders in RCA) were removed from SWEM and SWEM was re-run to generate results which were compared to the new ROMS-RCA water quality model results. Justification for removing the hardwires before comparing results is presented later.

Since HDR is familiar with RCA, the testing focused on whether ROMS-RCA could generally reproduce the SWEM model results, and if not, could the differences be explained. Additionally, model testing assessed whether the ROMS-RCA water quality model behaved as expected given changes to the model inputs (i.e., phytoplankton temperature optimums, zooplankton grazing). Finally, the model was tested to assess how inclusion of additional vertical layers would impact the model results, especially for dissolved oxygen (DO).

1.2. Shortcomings of SWEM

The University of Connecticut performed a detailed independent evaluation of the prior SWEM model (O'Donnell et al., 2010, 2014) and identified a number of shortcomings. For example, during the application and calibration of SWEM, the vertical eddy coefficients calculated by the hydrodynamic model (ECOM) were reduced in the water quality model (RCA) to improve model-data comparisons of near-bottom DO levels in western LIS during the summer. Although the vertical mixing adjustment in the water quality model was presented to and approved by the SWEM MEG at the time, it will not be adjusted in ROMS-RCA water quality model.

O'Donnell et al. (2014) noted that a comparison of SWEM ECOM results and observations in LIS indicate that the original vertical mixing values calculated by SWEM ECOM were actually realistic and that the mixing values imposed by the SWEM RCA vertical eddy coefficient reduction were much too small. In addition, observations in LIS indicated that both algal respiration and production were significantly underestimated in SWEM RCA (O'Donnell et al., 2010).

Recommendations from these evaluations included: eliminating vertical mixing adjustments in SWEM RCA, use of more recent estimates of algal respiration and production, refinement of the model grid to provide finer spatial (horizontal) resolution, and use of open-source models and data sharing standards (O'Donnell et al., 2014).

ROMS, and the increased computing power available since SWEM was developed, provide the opportunity to refine the model grid with finer spatial resolution and use an open-source model with data sharing standards. Better horizontal and vertical resolution as well as direct coupling between ROMS and RCA should eliminate the need for vertical mixing adjustments in RCA. Finer horizontal model grid resolution allows the model to develop stronger vertical density gradients by improving lateral mixing and reducing upslope mixing, which can reduce vertical mixing resulting in more vertical stratification. Also, direct coupling between the hydrodynamic and water quality models allows the models to communicate on a time-step basis and eliminates the need to average hydrodynamic model transport when transferring to the water quality model if the models are not directly coupled. When SWEM was developed, an hourly arithmetic average was used when saving hydrodynamic transport information for the water quality model. HDR's experience with ECOM and RCA since then has indicated that an arithmetic average assigns excessive weight to short term, high mixing events resulting in too much vertical mixing. For these reasons, HDR believes that a finer horizontal model grid and direct coupling will help improve the hydrodynamic model calculation of vertical mixing and improve representation of vertical stratification.

1.3. RCA

RCA (Row Column Advance Ecological Systems modeling Program, AESOP) is a generalized water quality/ecosystem model, built on the WASP framework (originally developed by HDR modeling staff) that is capable of being linked to the ECOM, EFDC, and ROMS hydrodynamic models. The RCA model includes full eutrophication kinetics to model nutrients, suspended algae, light and DO including a sediment flux submodel that calculates sediment nutrient fluxes and sediment oxygen demand as a function of settled organic matter. The RCA model is routinely used for complex nutrient assessments in estuaries, rivers, and lakes.

The principal attributes of the RCA source code include:

- RCA is a general-purpose code used to evaluate a myriad of water quality problem settings. The user can customize an RCA sub-routine to address water quality issues that are specific to a given water body.

- RCA formulates mass balance equations for each model segment for each water quality constituent or state-variable of interest. These mass balance equations include all horizontal and vertical components of advective flow and diffusive/dispersive mixing between model segments; physical, chemical, and biological transformations between the water quality variables within a model segment; and point, nonpoint, and atmospheric inputs of the various water quality variables of interest.

- The partial differential equations, which form the water quality model, together with their boundary conditions, are solved using several mass conserving finite difference techniques.

1.4. ROMS-RCA Code Development

As was noted earlier, Testa et al. (2014) coupled ROMS and RCA for use in Chesapeake Bay. The version of RCA that was applied in Chesapeake Bay, however, was an older version of the RCA model. Since ROMS is an open-source model, there were also changes made to multiple ROMS subroutines since the Chesapeake Bay application. In short, the RCA coupling to ROMS had to be redone for the LIS application. The ROMS-RCA development included the following steps:

1. Input/Output (I/O)

   I/O was tested to check how ROMS loads data into the model and how it handles reading and writing with external NetCDF files. A custom conservative tracer was added to ROMS-RCA, initially with no kinetics, to see how the tracer was read and written.

2. Physical Processes

   Advection and mixing of the conservative tracer were next added to the ROMS-RCA model. A mass balance analysis was conducted to ensure the model conserved mass.

3. Simple Water Quality Kinetics

   a. A new tracer was added to the code to test how the tracer moved through the code.
   b. Simple kinetics (i.e., first-order decay) were applied to the tracer to assess how the code processed the kinetics.

4. RCA Water Quality

   a. Twenty-six RCA-state-variables (see Table 1) were first added to the ROMS-RCA model code without kinetics and tested. This included two- and three-dimensional parameter inputs.
   b. Next the full eutrophication kinetics for the 26 RCA-state-variables were added to the model and tested.

5. Additional Inputs

   a. Atmospheric deposition was added to the ROMS-RCA model code.
   b. Temporally and spatially variable light extinction coefficient input capability was added to the ROMS-RCA model code.

6. Sediment Nutrient Flux Model

   The sediment nutrient flux model was added to the ROMS-RCA model code. Testing assessed the passage of information between the water quality and sediment flux submodels.

7. Restarts

   Code was added to the ROMS-RCA model so that it could restart from the end of a previous model run (hot-start). Currently, we are using 30-day model simulation time periods and this code feature allows starting the model roughly every month and avoids having to run a full year simulation (i.e., August can be run only without having to run January through August). Additionally, hot-starting the model is quite useful when investigating a model run "crash".

8. Total Suspended Solids (TSS) State-Variable

   SWEM did not include TSS as a state-variable and the typical RCA code did not either. Since it was desired to assess the impacts of TSS on light extinction for the LIS application, a TSS state-variable was added to the ROMS-RCA code. Since SWEM did not include TSS loading as part of its input, TSS was not included in the ROMS-RCA model testing. TSS will be included in the CY05-06 ROMS-RCA preliminary calibration.

After these steps were completed satisfactorily, SWEM inputs for WY95 were assigned in the ROMS-RCA water quality model to complete the testing.

Table 1. RCA Model State-Variables

State-Variable	RCA Name	State-Variable	RCA Name
Salinity	SAL*	Algal Nitrogen + Ammonia Nitrogen	NH4T
Phytoplankton Carbon Group 1	PC1	Nitrite+Nitrate Nitrogen	NO23
Phytoplankton Carbon Group 2	PC2	Biogenic Silica	BSI*
Phytoplankton Carbon Group 3	PC3	Algal Silica + Available Silica	SIT
Refractory Particulate Organic Phosphorus	RPOP	Refractory Particulate Organic Carbon	RPOC
Labile Particulate Organic Phosphorus	LPOP	Labile Particulate Organic Carbon	LPOC
Refractory Dissolved Organic Phosphorus	RDOP	Refractory Dissolved Organic Carbon	RDOC
Labile Dissolved Organic Phosphorus	LDOP	Labile Dissolved Organic Carbon	LDOC
Algal Phosphorus + Dissolved Inorganic Phosphorus	PO4T	Algal Exudate Dissolved Organic Carbon	ExDOC*

Table 1. RCA Model State-Variables			
State-Variable	**RCA Name**	**State-Variable**	**RCA Name**
Refractory Particulate Organic Nitrogen	RPON	Reactive Particulate Organic Carbon	RePOC
Labile Particulate Organic Nitrogen	LPON	Reactive Dissolved Organic Carbon	ReDOC
Refractory Dissolved Organic Nitrogen	RDON	Dissolved Oxygen Equivalents	O2EQ*
Labile Dissolved Organic Nitrogen	LDON	Dissolved Oxygen	DO
* - State-variable does not require load development.			

2. ROMS-RCA Model Development

2.1. Hydrodynamics

For the ROMS-RCA model, hydrodynamic information (volumes, water elevation, currents, water temperature, and salinity) is provided by the ROMS. Moreover, ROMS and RCA are run simultaneously (direct coupling) In the SWEM ECOM-RCA coupling, ROMS output is averaged and saved in separate output files for reading into RCA.

To minimize differences between the models and to be consistent with SWEM, the Mellor-Yamada level 2.5 turbulent closure scheme (k-kl) was used for ROMS. The application of ROMS used for the WY95 testing (HDR, 2022) was applied for the ROMS-RCA testing.

2.2. River Loads

River loads were assigned to 28 tributaries in SWEM using flow data compiled from USGS sites in New York, New Jersey, and Connecticut. Tributary concentrations were assigned monthly based on monitoring data collected at nine locations during the SWEM sampling program. Locations that were not monitored were assigned concentrations based on similar rivers that had measurements (HydroQual, 2001a).

The rivers included in SWEM were also included in the ROMS-RCA testing. The river input locations were re-mapped onto the new LIS model grid. In some cases, the new LIS model grid includes additional segmentation further up the rivers than in SWEM (e.g., Connecticut River). In those cases, the river loads were assigned to a river model cell where the new river input is located.

2.3. Point Source Loads

Major municipal wastewater resource recovery facilities (WRRFs) and industrial treatment plants were included in SWEM on a monthly input basis. The loadings were primarily developed using discharge monitoring report (DMR) data from the EPA Permit Compliance System (PCS). The data were supplemented with additional data collected by various municipalities during the SWEM monitoring program. In some cases, correlations between constituents were developed for some constituents that were not directly measured at all facilities (HydroQual, 2001a). The point source input locations were re-mapped onto the new LIS model grid.

2.4. Nonpoint Source Loads

In the SWEM application of RCA, combined sewer overflows (CSOs) and storm sewers loads were assigned to the nonpoint source loading file to separate them from the WRRFs. CSO and stormwater flows for NYC were calculated use the Rainfall Runoff Modeling Program (RRMP) II software, a simplified version of the Storm Water Management Model (SWMM). A separate, simpler RRMP program was used for New Jersey and Westchester County flows. CSO and stormwater pollutant concentrations were assigned using data collected during the SWEM monitoring program. LIS runoff loadings were based on loads developed during the Long Island Sound Study (HydroQual, 2001a). The nonpoint source input locations were re-mapped onto the new LIS model grid.

2.5. Atmospheric Loads

Deposition of nitrogen, phosphorus, silica, and carbon resulting from direct precipitation to surface waters were included in the SWEM model as atmospheric loading inputs. Loading estimates were based on atmospheric wet deposition data collected during the SWEM monitoring program at 10 locations (HydroQual, 2001a). Loads were applied on a monthly basis and were spatially uniform.

2.6. Oceanic Boundary Conditions

SWEM oceanic boundary conditions were based on monitoring data collected near the model offshore boundary. The chosen monitoring stations were considered far enough away from NY/NJ Harbor and LIS to be considered unimpacted by loads internal to the domain of SWEM (HydroQual, 2001b). Oceanic boundary conditions were re-mapped onto the new LIS model grid.

2.7. Time-Variable Functions

RCA requires time-variable inputs beyond information from the hydrodynamic model and external loadings. These inputs include solar radiation and fraction of daylight, which impact the growth of phytoplankton. Solar radiation was based on cloud cover estimates from Central Park and was varied on an hourly basis but assigned spatially constant throughout the model domain. The daily fraction of daylight was used to calculate hourly solar radiation estimates and was spatially constant (HydroQual, 2001b).

2.8. Constants

The model constants applied in SWEM were assigned to the ROMS-RCA model for the WY95 testing (HydroQual, 2001b). For example, model constants include algal growth and respiration, zooplankton grazing, organic carbon oxidation and atmospheric reaeration.

2.9. Changes from SWEM

In some cases, SWEM had “hardwired” coding changes outside the standard RCA code. These changes included artificially reducing the ECOM calculated vertical mixing during portions of the year, applying spatially varying enhanced settling to simulate the effect of benthic filter feeders, setting a minimum air temperature, and specifying monthly zooplankton grazing rates. These features were not applied in the testing of the old SWEM-RCA and new ROMS-RCA water quality models.

3. Comparisons to SWEM

3.1. Base Condition Model Setup

A base condition in ROMS-RCA was developed for comparison to the original SWEM RCA results, without model “hardwires” and to complete model sensitivities. The base condition included the same constants and parameters as used in SWEM RCA with one exception. Since winter temperatures in ROMS are lower than in ECOM, the temperature effect on algal growth for the winter phytoplankton group was modified. The optimum temperature for growth of the winter phytoplankton group was assigned to 8°C in SWEM RCA, and ultimately in ROMS-RCA. Since lower temperatures were calculated in ROMS, the ROMS-RCA winter phytoplankton bloom was delayed as compared to SWEM RCA in initial ROMS-RCA model runs. To offset this effect, a change was made to the shaping parameter of the algal growth temperature function. As temperature deviates from the optimum temperature, the maximum growth rate is reduced, and the rate of reduction is controlled by a temperature function controlled by shaping parameters for either temperatures higher or lower than the optimum temperature. To account for the lower temperatures in ROMS, the shaping parameter for the winter phytoplankton group was set to 0.0 from 0.004 to allow the maximum growth rate to occur at all temperatures less than or equal to 8°C. Figure 1 presents the winter algal growth temperature functions used in the SWEM RCA and ROMS-RCA models.

While this approach did not create an exact match between SWEM RCA and ROMS-RCA model results, it reduced the differences, so it would be easier to compare SWEM RCA and ROMS-RCA results.

3.2. Temperature and Salinity

Although temperature and salinity are calculated in the hydrodynamic models (SWEM ECOM, ROMS) and were discussed in the ROMS WY95 model testing memo (HDR, 2022), further discussion of is included in this memo as temperature and salinity affect ROMS-RCA calculated water quality parameters.

The temperature and salinity calculated by ROMS differed from the temperature and salinity calculated by SWEM ECOM and that impacted the ROMS-RCA water quality model calculations. Reasons for the differences include:

- The ROMS-RCA water quality model is directly coupled with the ROMS hydrodynamic model, while the SWEM ECOM and RCA models are not directly coupled (i.e., SWEM RCA reads ECOM saved model transport).
- The ROMS hydrodynamic model was not calibrated for WY95, it was only setup and tested.
- The SWEM ECOM model included a “hardwire” that did not allow winter air temperatures to drop below 4°C. This “hardwire” affected the atmospheric heat exchange calculations in SWEM ECOM and resulted in ECOM water temperatures in the winter reaching a minimum of about 3-5°C. No such “hardwire” was included in the ROMS hydrodynamic model, which resulted in minimum winter temperatures of around 0°C.
- The finer spatial resolution of the LIS model grid and associated bathymetry used with ROMS-RCA resulted in different mixing patterns in the model.

Figure 2 presents temperature comparisons for SWEM ECOM and ROMS at eight example stations. The station numbers are based on the original Battelle sampling station numbers for the WY95 monitoring. The model results in these figures, as well as all other figures in this memo, were smoothed by 24-hour moving averages. This was done to remove some of the intraday variability in the model results to make the comparisons between the two models easier.

ROMS reached lower temperatures during January through March and takes another few months to match the late spring temperatures calculated in ECOM. Temperatures are important in the RCA water quality model because water temperature affects kinetic rates (e.g., algal growth and respiration) in the model. The lower temperatures calculated with ROMS in the winter and spring will delay the onset of the calculated winter/spring algal bloom in ROMS-RCA. The lower temperatures will also affect algal respiration rates, carbon oxidation rates, and atmospheric reaeration rates, all of which impact DO concentrations. Compared to ECOM, temperatures were also as stratified between the surface and bottom in ROMS during the summer except at station 200. In places where there was less temperature stratification, there was also less DO stratification (see Section 3.6). Since the hydrodynamic model calculated temperatures between the two models do not match, the ROMS-RCA water quality model results will not match, even when using the same SWEM RCA model inputs.

Figure 3 presents salinity comparisons between SWEM ECOM and ROMS. The salinity results were similar between the two models but there are some differences. In places where large amounts of freshwater mix with marine water, the between-model salinity differences tended to be larger (e.g., East River at station 58 and Hudson River station 166). This is likely due to the differences in model grid resolution and associated bathymetry as well as the differences in bottom roughness coefficients applied between the two models. SWEM used variable bottom roughness coefficients to offset the effects of the coarser SWEM model grid resolution in the East River.

Salinity differences can affect the water quality results (e.g., DO saturation, dilution of loads) but can also affect density stratification, which can affect how quickly oxygen from atmospheric reaeration reoxygenates bottom waters. Density differences can also drive currents causing load distribution differences. When salinity differences are largest, the largest differences in mixing between the models will also be observed.

Because of between-model differences in temperature and salinity, differences between SWEM RCA and the ROMS-RCA are expected, and differences observed during testing does not mean the ROMS-RCA water quality model is not working correctly.

3.3. Total Nitrogen

Constituents such as total nitrogen (TN) and total phosphorus (TP) are close to behaving as conservative tracers (i.e., no loss). TN does include an additional loss due to denitrification. Comparing the TN concentrations of the two models indicates whether the same amount of mass is being accounted for in both models. TP model results are not presented as nitrogen typically limits algal growth in LIS. TP model results and data will be presented for model calibration and validation. Figure 4 shows a comparison of TN between SWEM RCA and ROMS-RCA at eight locations. In places where the salinity is comparable between the two models, the TN is also similar. In places where the differences in salinity were larger, the differences in TN also tended to be larger. TN results are reasonable and indicate that the ROMS-RCA model is conserving mass.

3.4. Chlorophyll-a

The growth of phytoplankton is affected by light, temperature, and nutrients. The concentrations of phytoplankton are also affected by transport and mixing. Since the temperature was different between the two models, especially during the winter, the temperature optimum and temperature shaping parameter for the winter phytoplankton group was modified in ROMS-RCA to better match the SWEM RCA results (see Section 3.1). This was done to see how the algal growth coefficient adjustments can modify chlorophyll-a calculations using the ROMS calculated temperatures. Overall, the two models produce similar chlorophyll-a concentrations and similarly timed algal blooms (Figure 5). Specifically, the difference in model temperatures and the revised algal growth temperature shaping parameter resulted in ROMS-RCA and SWEM RCA yielding similar winter algal peak concentrations and it resulted in ROMS RCA having an earlier winter bloom onset than SWEM RCA. Further modification of the model algal growth constants would be necessary for them to match more closely, but that was not the goal of the model testing.

The ROMS-RCA summer bloom was smaller than the winter bloom, in part, due to zooplankton grazing. In the original SWEM RCA, zooplankton grazing was "hardwired" as a constant that changed monthly. This "hardwire" was removed and replaced with the typical RCA functionality where the zooplankton grazing rate increases with temperature. Since the summer has the highest temperatures, higher grazing rates reduced the summer phytoplankton bloom as compared to SWEM RCA. The summer blooms were fairly comparable between the two models. The noted results indicate that the ROMS-RCA phytoplankton kinetics are working properly.

3.5. Dissolved Inorganic Nitrogen (DIN)

As phytoplankton use inorganic nutrients for growth, they affect the inorganic nutrient concentrations in the water column. Higher phytoplankton biomass, as indicated by higher chlorophyll-a levels, result in lower inorganic nutrient concentrations. The inorganic nutrient concentrations are also impacted by transport and fluxes to and from the sediment. Figure 6 presents a comparison of DIN model results at eight stations for SWEM RCA and ROMS-RCA. Since ROMS-RCA had an earlier onset of the winter algal bloom, DIN concentrations decreased earlier than in SWEM RCA, as would be expected. In places where DIN was more abundant and not as affected by algal uptake, such as at station 58, the differences in DIN between the two models were not as noticeable. The similar patterns and magnitude of DIN results from the two models indicate that ROMS-RCA is working properly.

3.6. Dissolved Oxygen

DO is the most complicated constituent in the water quality model as it has multiple sources and sinks. As other components diverge between the two models, they can result in an additive divergence between the two models for DO. Figure 7 shows a comparison between DO concentrations for the two models at eight locations. Lower winter temperatures and higher phytoplankton biomass resulted in higher winter DO in ROMS-RCA as compared to SWEM RCA. The lower winter temperatures and higher biomass prevented ROMS-RCA from matching the SWEM RCA DO results later in the year during the spring. By the summer, the ROMS-RCA surface DO tended to be similar to the SWEM DO results, however, the bottom ROMS-RCA DO was higher than that calculated in SWEM RCA. The DO seasonal trends of both models were similar, but the ROMS-RCA DO was consistently higher. The preliminary ROMS-RCA calibration to CY05-06 will be used to further evaluate DO concentrations observed throughout the year.

3.7. Assessment of Comparison between SWEM RCA and ROMS-RCA

Initial testing of ROMS-RCA using SWEM inputs indicate that ROMS-RCA is working properly (i.e., ROMS-RCA produces similar seasonal and spatial variations observed in the SWEM RCA results). Nonetheless, differences between the ROMS-RCA and SWEM RCA model results exist for several reasons. First, differences in ROMS and SWEM ECOM temperature and transport results translate into differences in water quality model results. Second, ROMS-RCA and SWEM use different model grids and bathymetry. Finally, and perhaps the biggest reasons for differences between the models, are SWEM-ECOMs air temperature hardwire and assigned spatially-variable bottom-friction. Additional model testing was conducted as presented in Section 4 to investigate a few ROMS-RCA model adjustments. Additionally, the ROMS-RCA water quality model will be further improved upon during model calibration to CY05-14.

4. ROMS-RCA Testing

Model testing was completed with the ROMS-RCA WY95 model to investigate the impact that a few model adjustments had on model results. These model test runs were completed to help guide model calibration to CY05-14 and included testing additional model vertical segmentation, algal growth temperature optimum, and zooplankton grazing rate.

4.1. Additional Model Vertical Segmentation

SWEM RCA was unable to reproduce the observed bottom DO concentrations during the summer in LIS without modification of the vertical mixing obtained from SWEM ECOM. Reasons for this could include the coarseness of the old model grid, information loss due to hourly arithmetic averaging of the ECOM transport output, or coarseness in the vertical resolution of the model. The finer ROMS-RCA model grid resolution addresses the coarseness of the model grid, and running ROMS and RCA simultaneously addresses the hydrodynamic model output averaging. Adding vertical model layers addresses whether increased vertical resolution improves the model's ability to reproduce summertime bottom DO concentrations. The results from the ROMS hydrodynamic model testing with additional vertical model layers were inconclusive and were further explored to determine the effect on water quality model results.

4.1.1. Temperature

A model run for the time period of June through August (stratified conditions) was completed to assess the impact of using 30 vertical-layers rather than 10 layers. Figure 8 presents a comparison of the temperature results from this test to the SWEM ECOM results. Even with the additional layers, ROMS temperatures were less stratified than the 10-layer SWEM ECOM (exception at station 200). The ROMS hydrodynamic model 30-layer temperature results did not change significantly over the modeled time period (i.e., positive and negative changes) from the ROMS 10-layer results, as was observed in the ROMS WY95 testing. Figure 9 presents the difference in temperature between the 30-layer and the base condition results. In general, there was no meaningful difference in surface and bottom temperature except at the ocean locations. These ocean locations may be affected by the assigned offshore boundary condition inputs and will be further evaluated during model calibration to CY05-14.

4.1.2. DO

Figure 10 shows 30-layer ROMS-RCA DO results and the SWEM RCA results. Since the temperature did not change much with the addition of more vertical layers in the ROMS hydrodynamic model, the DO concentrations did not change very much either. Figure 11 presents the DO differences between the 10-layer test run and 30-layer ROMS-RCA model results. In most cases, the change made to the number of vertical layers did not change the DO concentrations much (i.e., more than 1.5 mg/L).

Based on the DO testing results, it does not appear necessary to continue running the model with additional vertical segmentation for the model calibration. Additional vertical layers add to the model run time and this additional computational burden does not seem warranted at this time. Although the testing results did not indicate the need to use 30 vertical-layers, additional vertical layers will continue to be considered as an option for sensitivity testing as model calibration proceeds.

4.2. Phytoplankton Growth Temperature Optimum

The timing of algal blooms can be modified in the model by changing the optimum temperature and temperature shaping parameters for algal growth. A model test was conducted with ROMS-RCA for December through March by adjusting the temperature optimum for the winter phytoplankton group from

8°C to 4°C and returning the temperature shaping parameter back to the original constant used in SWEM RCA (i.e., 0.004). This test was an attempt to change the timing of the winter bloom since it occurred earlier in the ROMS-RCA base condition as compared to SWEM RCA.

4.2.1. Chlorophyll-a

The chlorophyll-a results are presented in Figure 12 and were nearly identical to the base condition. This was not the expected outcome based on previous model testing but is explained by a few observations.

- The temperature shaping parameter used in the base condition allowed the optimum temperature for algal growth to occur at any temperature below 8°C.
- For the phytoplankton temperature optimum test, the period modeled (December through March) did not vary much from 4°C and the temperature shaping parameter used did not result in a large change in the temperature adjusted algal growth rate.

Differences between the two model runs would have likely been more pronounced had the model been run for a longer period of time when temperatures exceeded the base condition temperature optimum of 8°C. The use of the temperature optimum for model calibration will continue to be used as part of the chlorophyll-a model calibration. Figure 13 shows that some changes to the chlorophyll-a concentrations between the base condition and testing results did occur due to the change in the temperature optimum, but the changes were minor (i.e., less than 1-2 ug/L).

The expected change associated with modifying the winter phytoplankton optimum temperature for growth was based on results from an earlier model testing run. Figure 14 shows these chlorophyll-a results using the constants applied in the base condition, but the model started in January with the chlorophyll-a initial conditions more closely matching the SWEM RCA results. The results from this testing run suggested that the chlorophyll-a starting point (i.e., initial conditions) has a large effect on the timing of the winter bloom. The results shown in Figure 14 indicated that reproducing the SWEM RCA winter algal bloom is a function of the starting point and that reproducing prior algal levels will be an important part of reproducing the winter algal bloom. This same observation will hold true for reproducing other algal blooms throughout the year.

4.3. Zooplankton Grazing Rate

SWEM RCA assigned zooplankton grazing on a monthly basis based on monitoring data. This approach is acceptable for an annual calibration but is less useful for a multi-year analysis or for assessing how grazing might change with load reductions that change phytoplankton biomass. For the base condition, the SWEM RCA assigned grazing rate was replaced with a grazing rate that increased with temperature, which is the standard RCA formulation. This test used a constant grazing rate of 0.05/day at 20°C that is adjusted based on the model calculated temperature. The run was completed for June and July. The ROMS-RCA zooplankton grazing rate test resulted in lower grazing rates as compared to those used in SWEM RCA.

4.3.1. Chlorophyll-a

With the zooplankton grazing of phytoplankton reduced in the summer for the grazing rate test, phytoplankton algal biomass increased. As shown in Figure 15, chlorophyll-a concentrations increased the most at the western LIS stations where high DIN concentrations occurred. In more nutrient limited areas (eastern LIS), the zooplankton grazing rate decrease did not change chlorophyll-a concentrations as much. Figure 16 shows the difference in chlorophyll-a between the grazing rate test and the base condition. Figure 17 shows that in areas where chlorophyll-a increased, DIN concentrations decreased as would be expected.

4.3.2. DO

The grazing rate test resulted in increased phytoplankton biomass and, consequently, more photosynthesis and oxygen production. Figure 18 shows the change in oxygen concentrations between the grazing rate test and base condition. Larger changes to DO occurred in western LIS as compared to eastern LIS locations.

The Connecticut Department of Energy and Environmental Protection (CTDEEP) does have zooplankton biomass measurements in LIS for the model calibration and validation time periods. Zooplankton will not be modeled directly, but the biomass data will be used to estimate when the grazing pressure on algal biomass is highest and to help develop a grazing rate formulation. It will be important to model the temporal and spatial grazing rate with some accuracy to properly model phytoplankton and the effects on nutrients and DO.

5. Conclusions and Implications for CY05-06 Preliminary Calibration

The RCA water quality model was coded into the version of ROMS in use for LIS and then tested and compared to prior SWEM RCA model results. Model inputs from SWEM ECOM and RCA were used to setup ROMS-RCA for. The SWEM RCA model results were compared to the ROMS-RCA results to assess whether the ROMS-RCA results were reasonable and if the model was working as expected. Initial testing showed that the updated ROMS-RCA model is working properly even though the ROMS-RCA model did not exactly reproduce the SWEM RCA model results. Among other reasons, differences were expected because of differences in model segmentation, hydrodynamic transport, and water quality kinetics.

The ROMS-RCA model was also used to complete a few test runs and the conclusions are summarized below.

- At this point, additional vertical layers have not proven to be beneficial in improving both hydrodynamic and water quality model results (i.e., better representation of vertical stratification processes). Due to the extra computational burden of using more vertical layers, the model calibration will continue using 10 vertical-layers. Although the testing results did not indicate the need to use 30 vertical-layers, additional vertical layers will continue to be considered as an option for sensitivity testing as the model calibration proceeds.
- Algal bloom timing is affected by the optimum temperature and temperature shaping parameters for algal growth assigned in the model. Although the test results were mixed, further exploration and adjustment of algal growth constants will be completed during model calibration with the understanding that algal bloom timing is also a function of pre-bloom phytoplankton levels.
- The zooplankton grazing rate was shown to be an important model input that can have significant impacts on the calculated phytoplankton concentrations. Use of the CTDEEP zooplankton biomass data in LIS to develop grazing rate inputs for the model calibration time period will be important in defining the phytoplankton loss rate.

It is expected that code changes to ROMS-RCA will be required during model calibration. Potential code changes may include:

- Revised formulations for atmospheric oxygen transfer, vertical light attenuation, algal respiration or other factors controlling nutrients, phytoplankton and DO.

- The addition of total suspended solids (TSS) as a state variable and other model constituents used to calculate light attenuation.
- The addition of a third algal group to better represent the annual phytoplankton growth cycle.
- Revisions to the zooplankton grazing formulation to better capture the seasonal cycle of zooplankton growth based on the CTDEEP data.

The next step in the ROMS-RCA water quality modeling is to complete the preliminary model calibration using CY05-06 data. Preliminary calibration of the ROMS hydrodynamic model for CY05-06 (HDR, 2022b) has produced encouraging results. In the testing of the ROMS hydrodynamic model using WY95 inputs, ROMS did not produce the same level of vertical stratification as was observed in either the data or SWEM ECOM output. For CY05-06, ROMS is reproducing observed temperature and salinity data, and observed temperature and salinity vertical stratification throughout the model study area. As water quality model results are highly dependent on hydrodynamic transport, it is anticipated that similar improvements will result from the ROMS-RCA preliminary calibration to the CY05-06 data.

6. References

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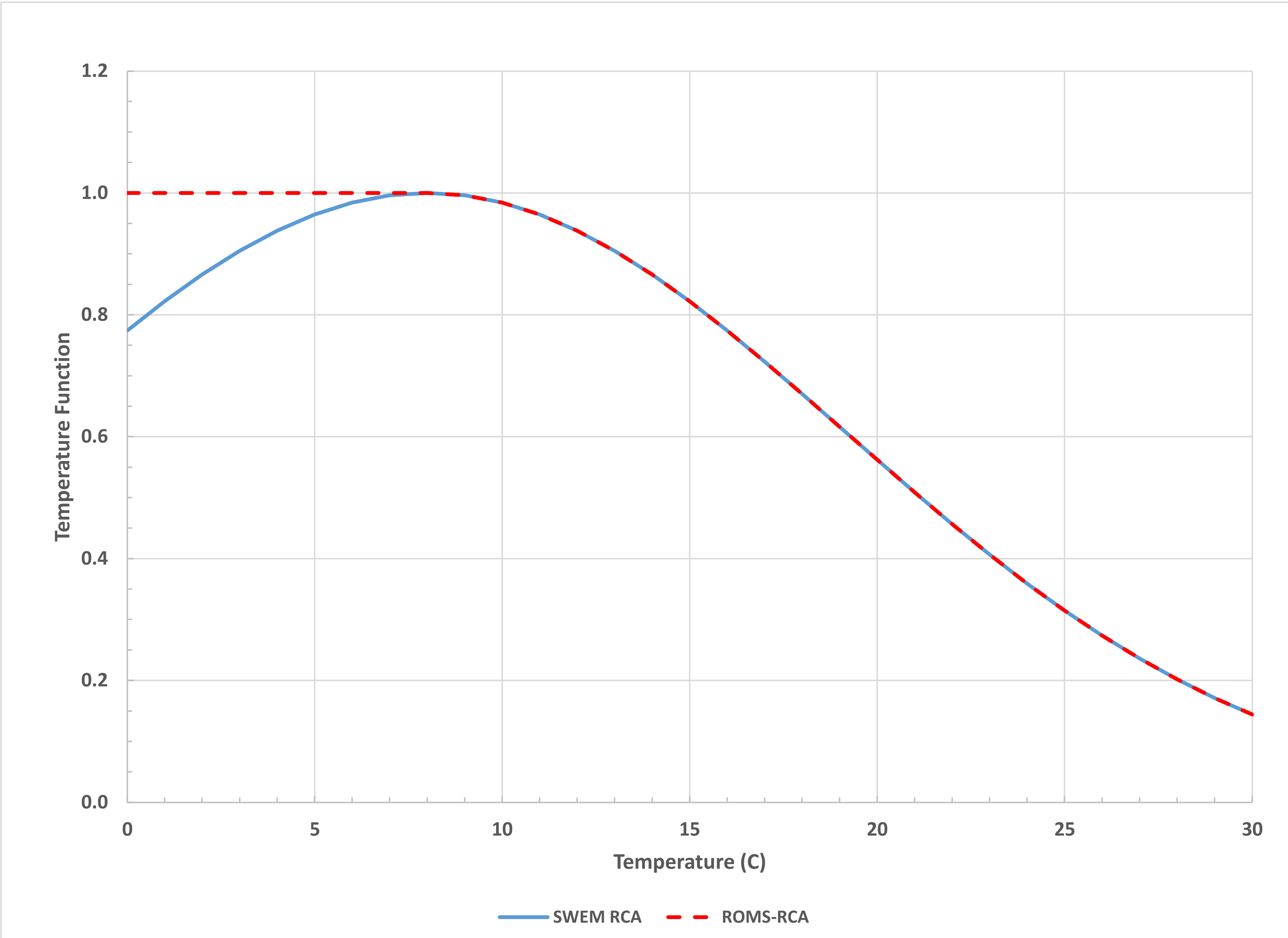


Figure 1. SWEM RCA and ROMS-RCA Winter Algal Growth Temperature Functions

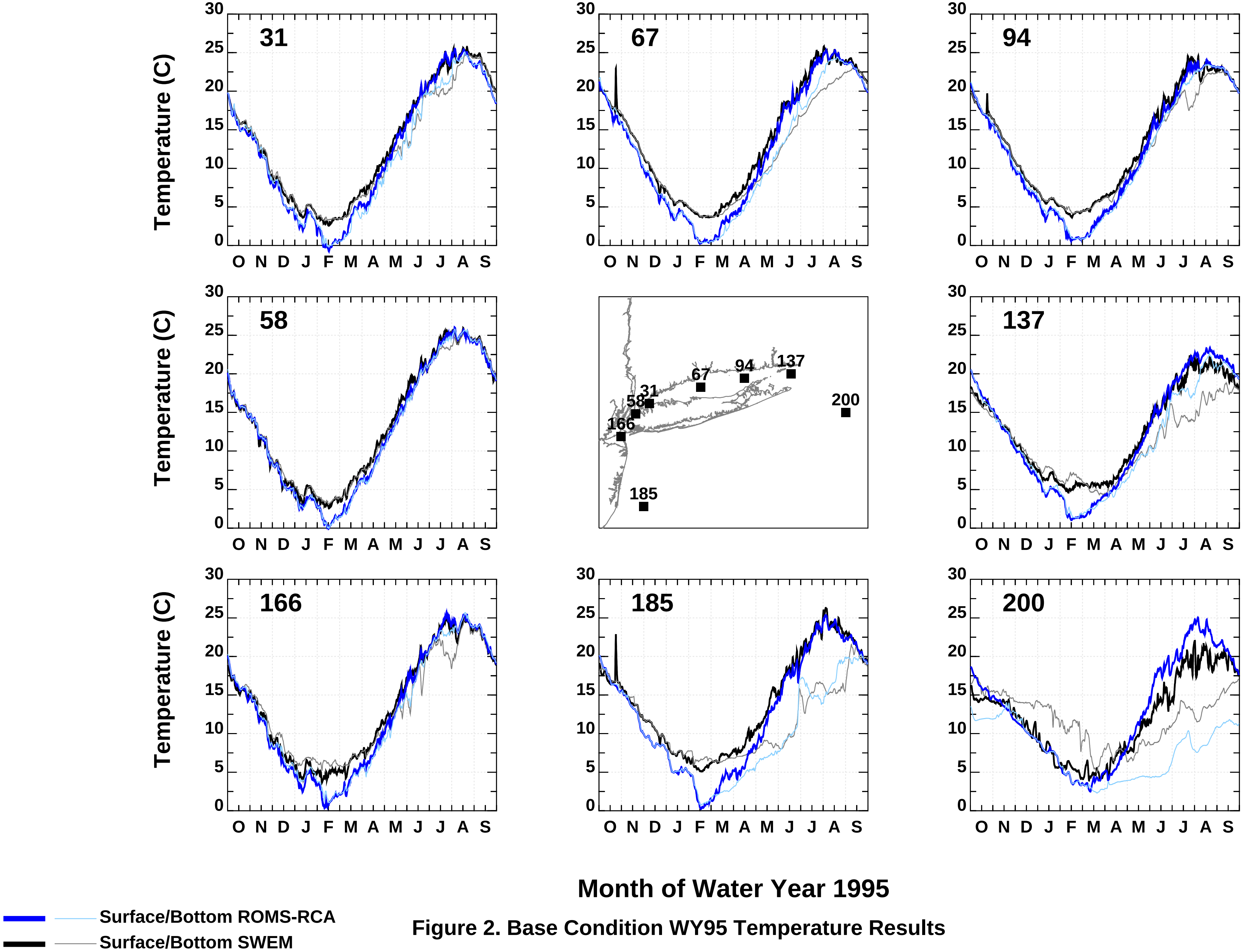


Figure 2. Base Condition WY95 Temperature Results

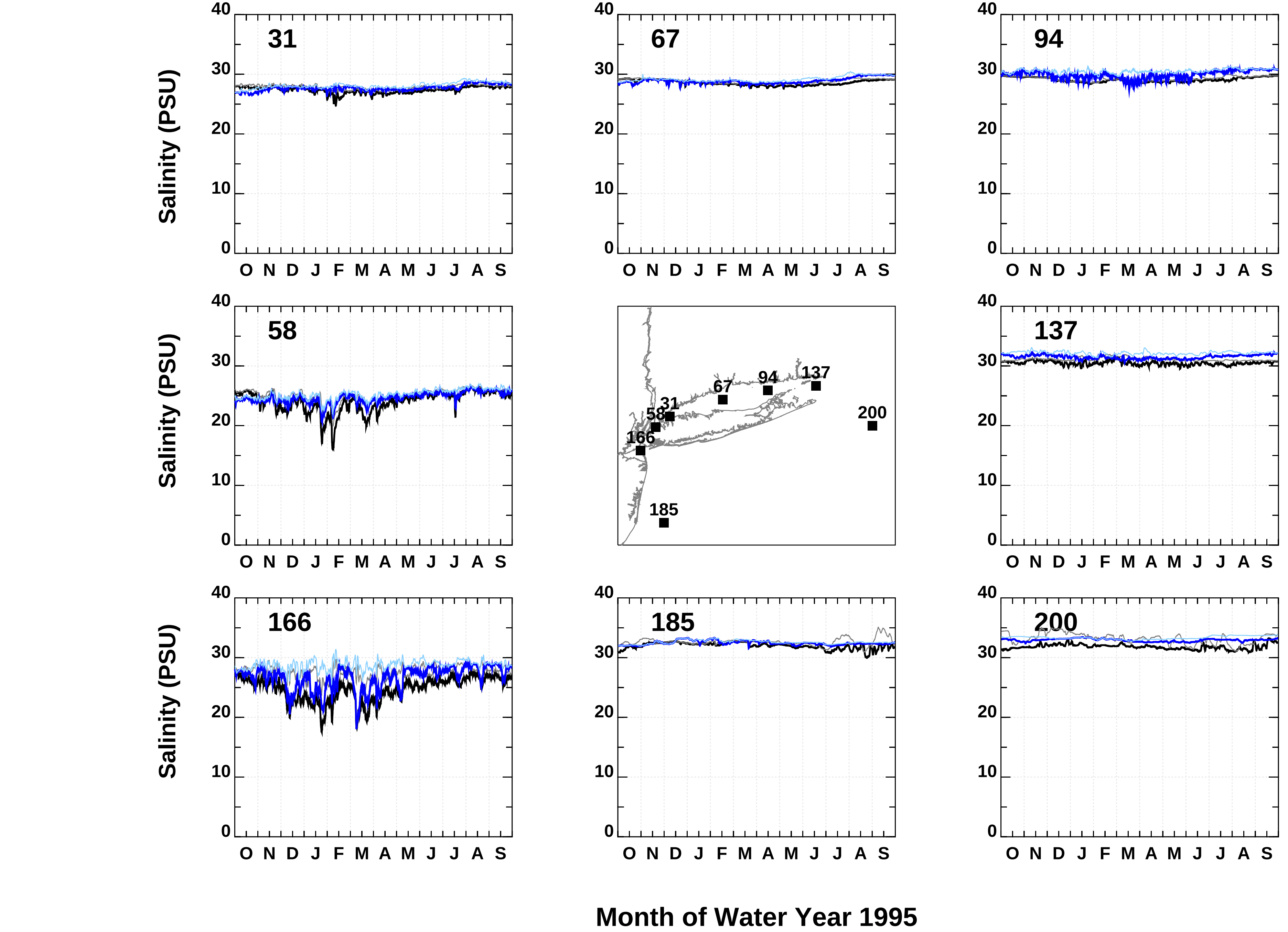


Figure 3. Base Condition WY95 Salinity Results

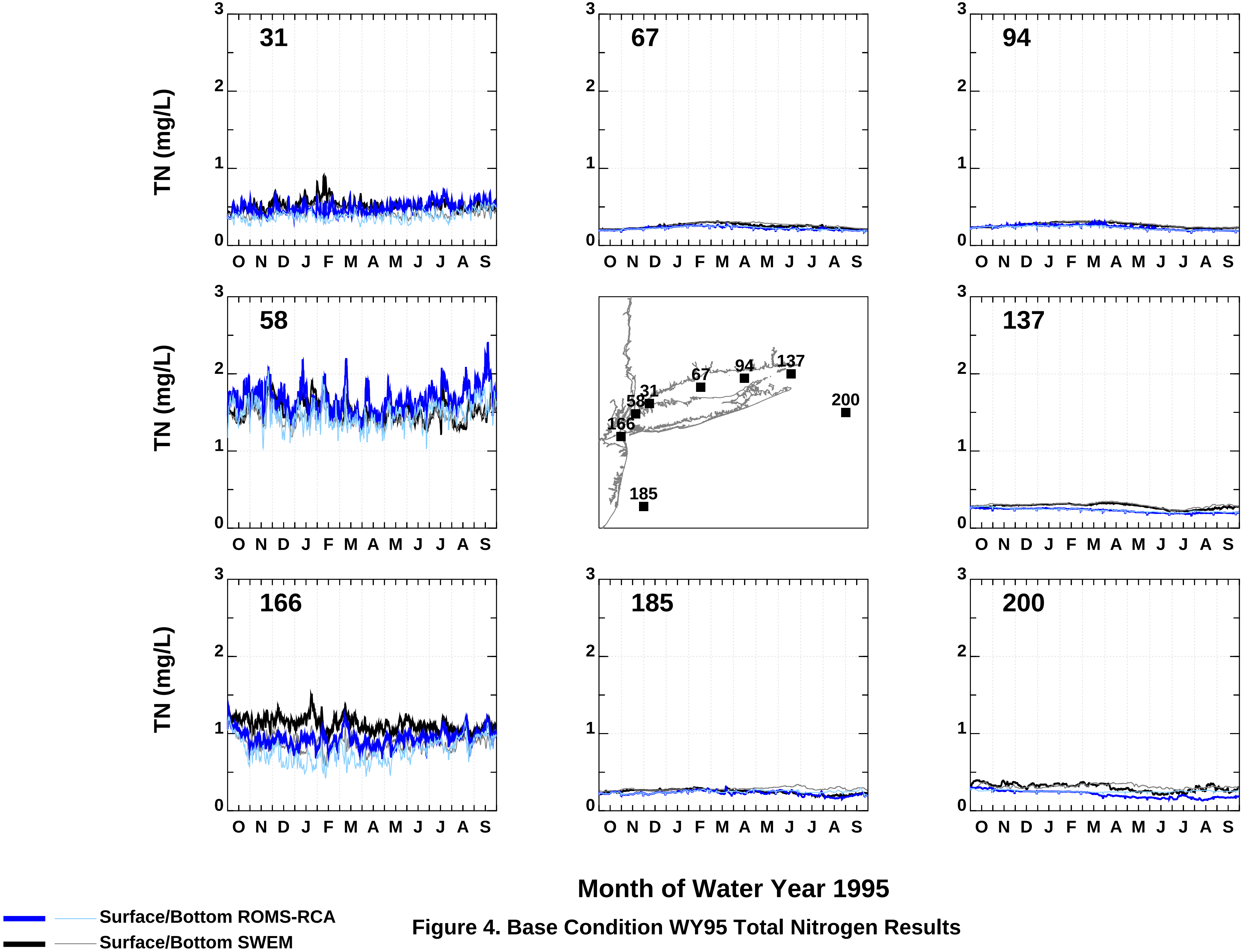


Figure 4. Base Condition WY95 Total Nitrogen Results

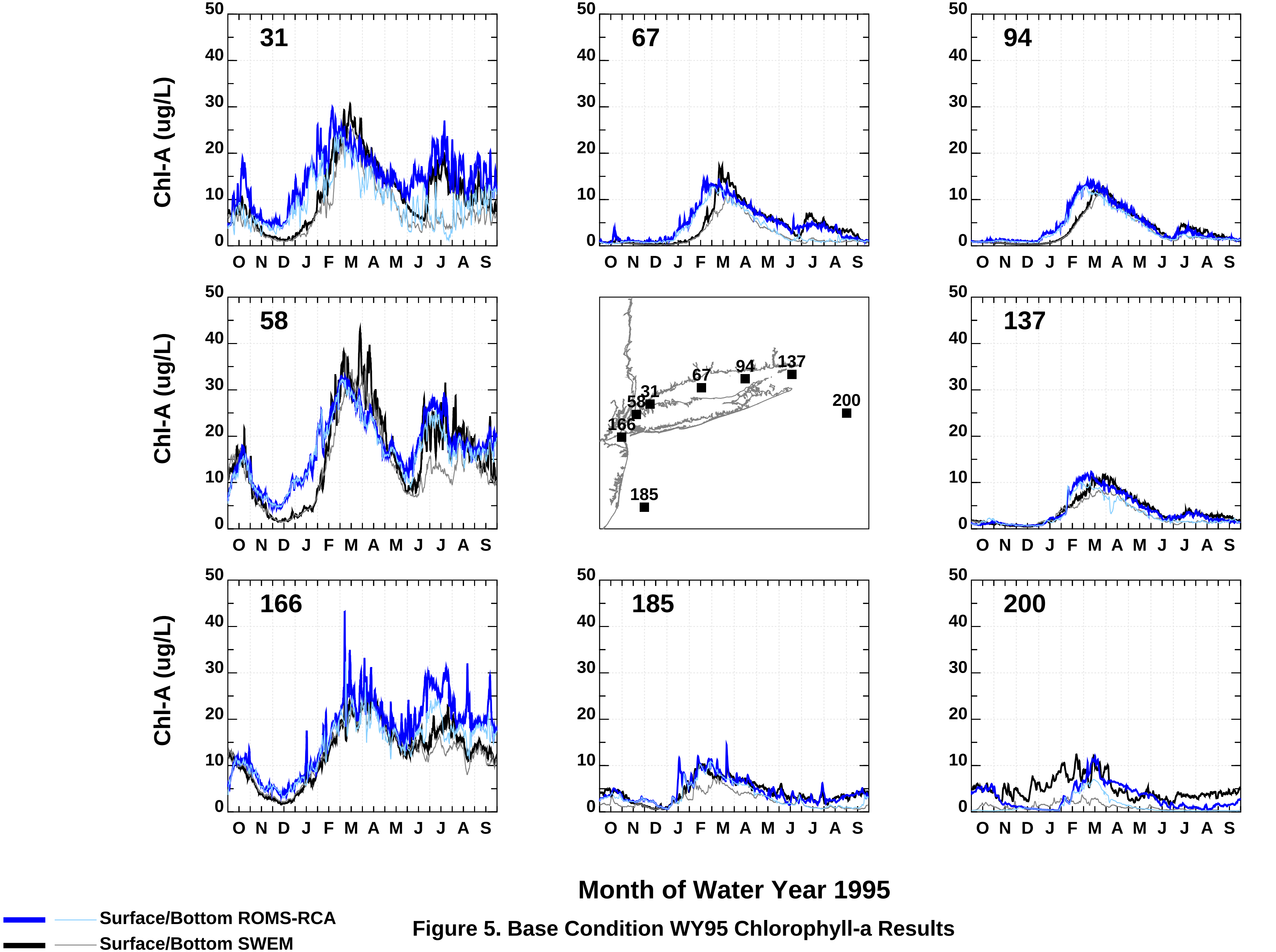


Figure 5. Base Condition WY95 Chlorophyll-a Results

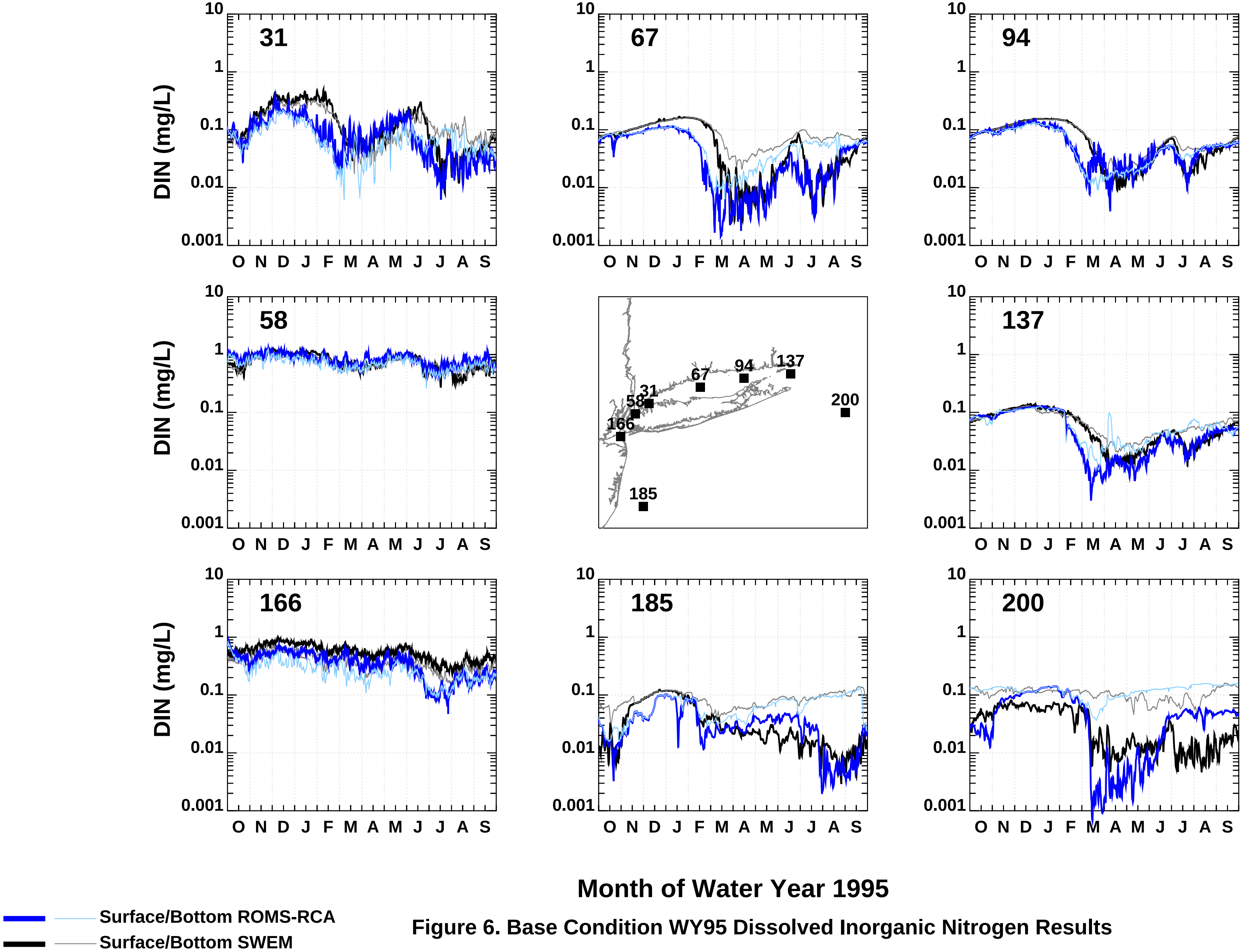
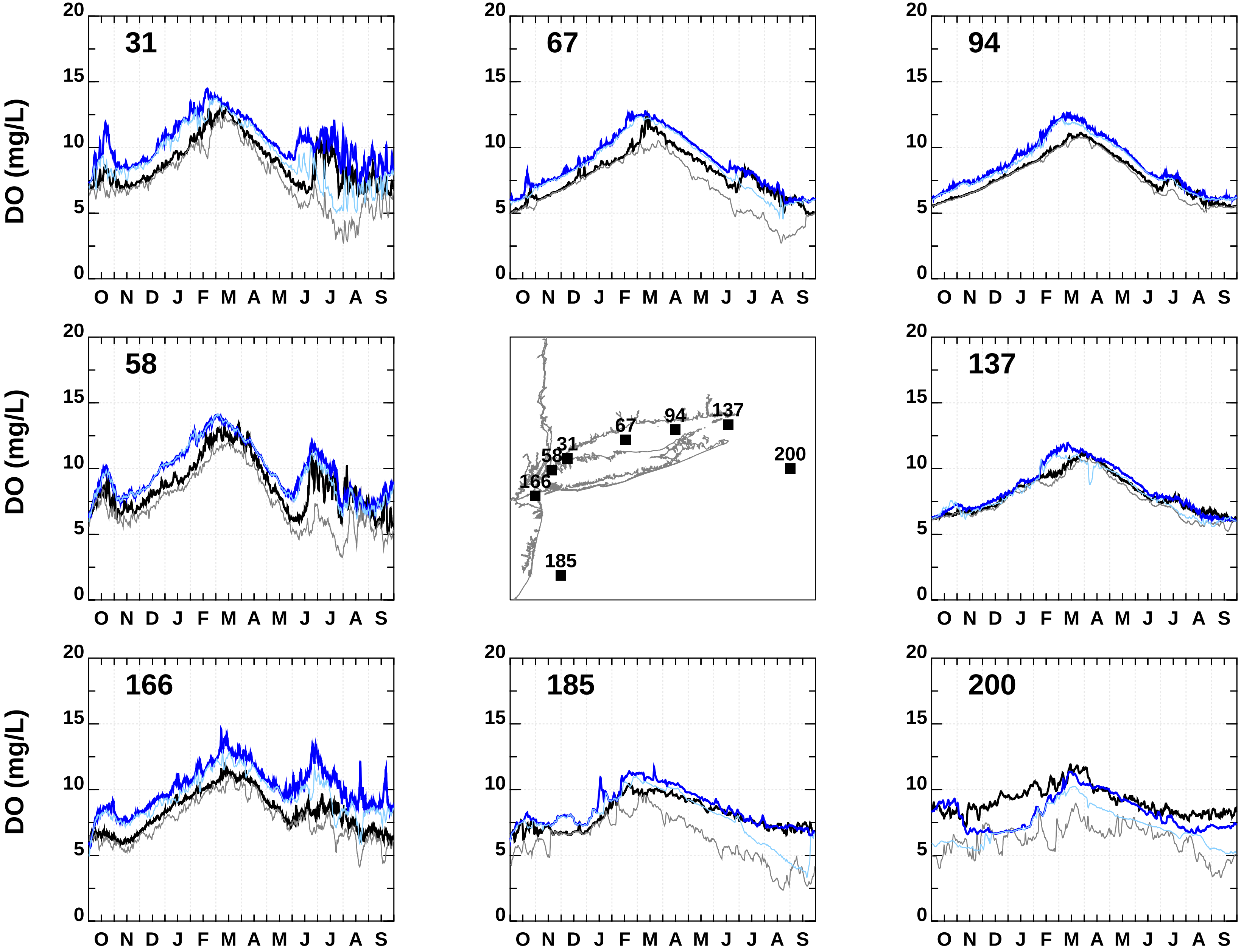


Figure 6. Base Condition WY95 Dissolved Inorganic Nitrogen Results



Month of Water Year 1995

Surface/Bottom ROMS-RCA

Surface/Bottom SWEM

Figure 7. Base Condition WY95 Dissolved Oxygen Results

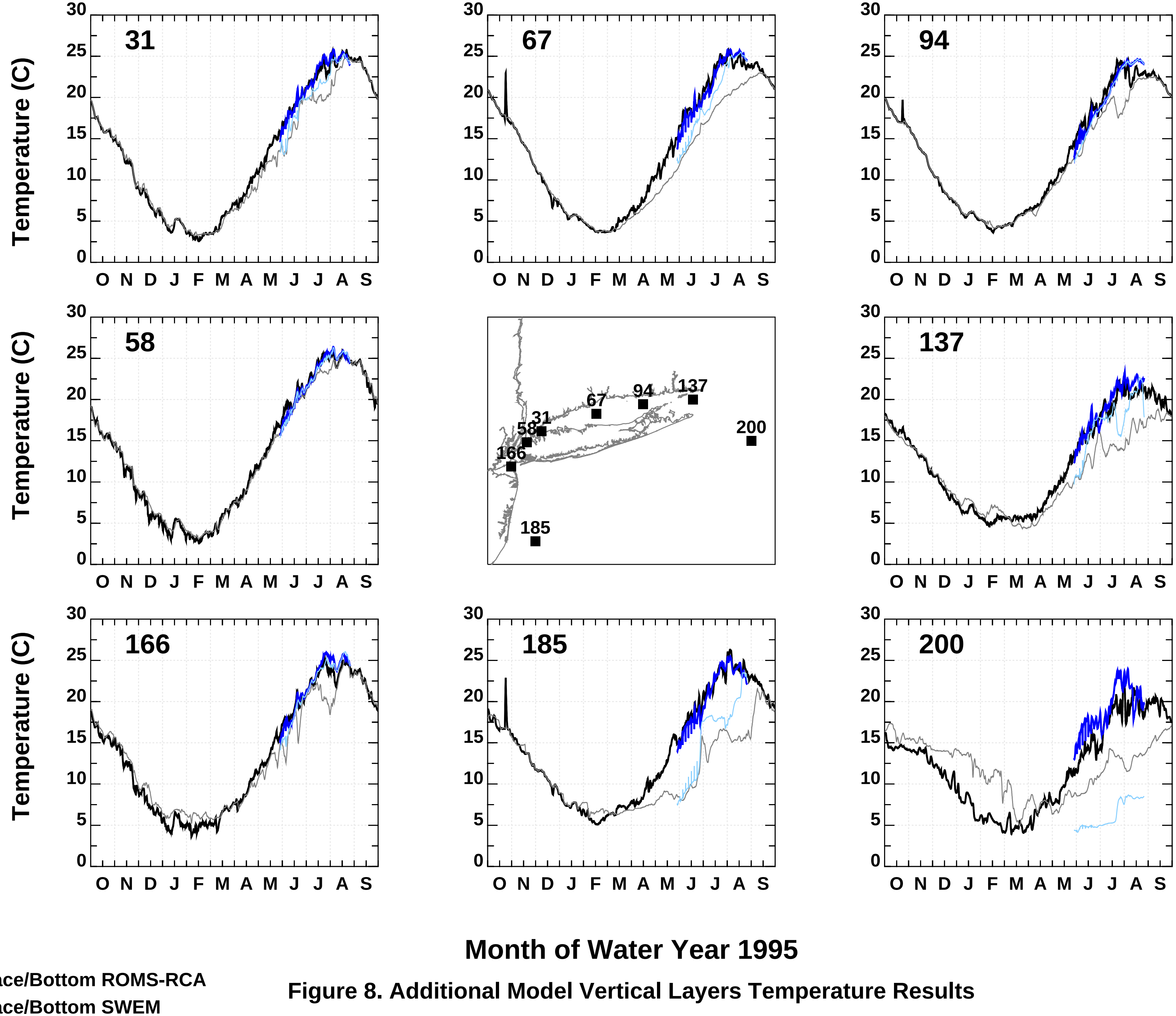
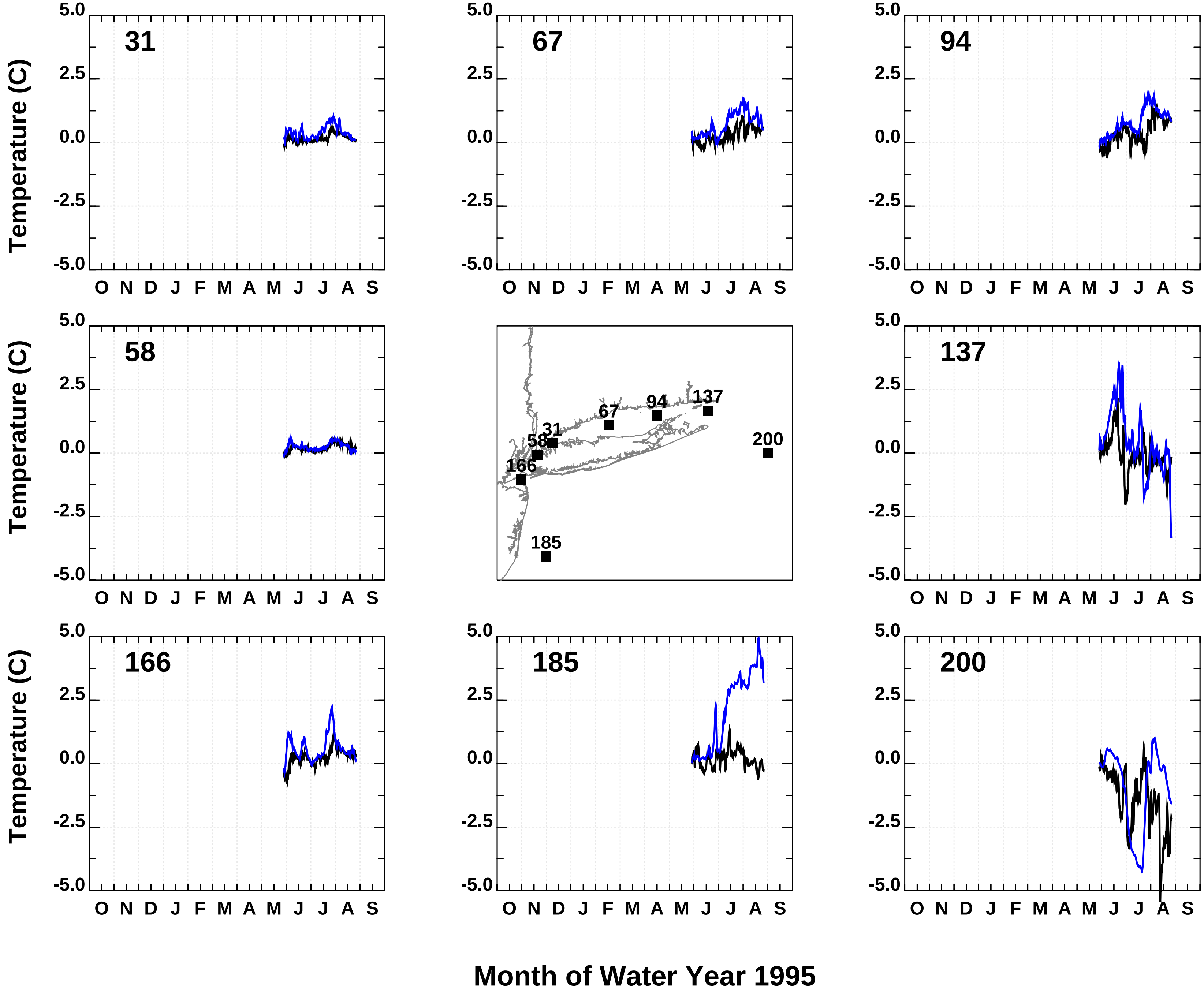


Figure 8. Additional Model Vertical Layers Temperature Results



Surface Difference (30-layer run - Base run)
Bottom Difference (30-layer run - Base run)

Figure 9. Additional Model Vertical Layers Temperature Difference Results

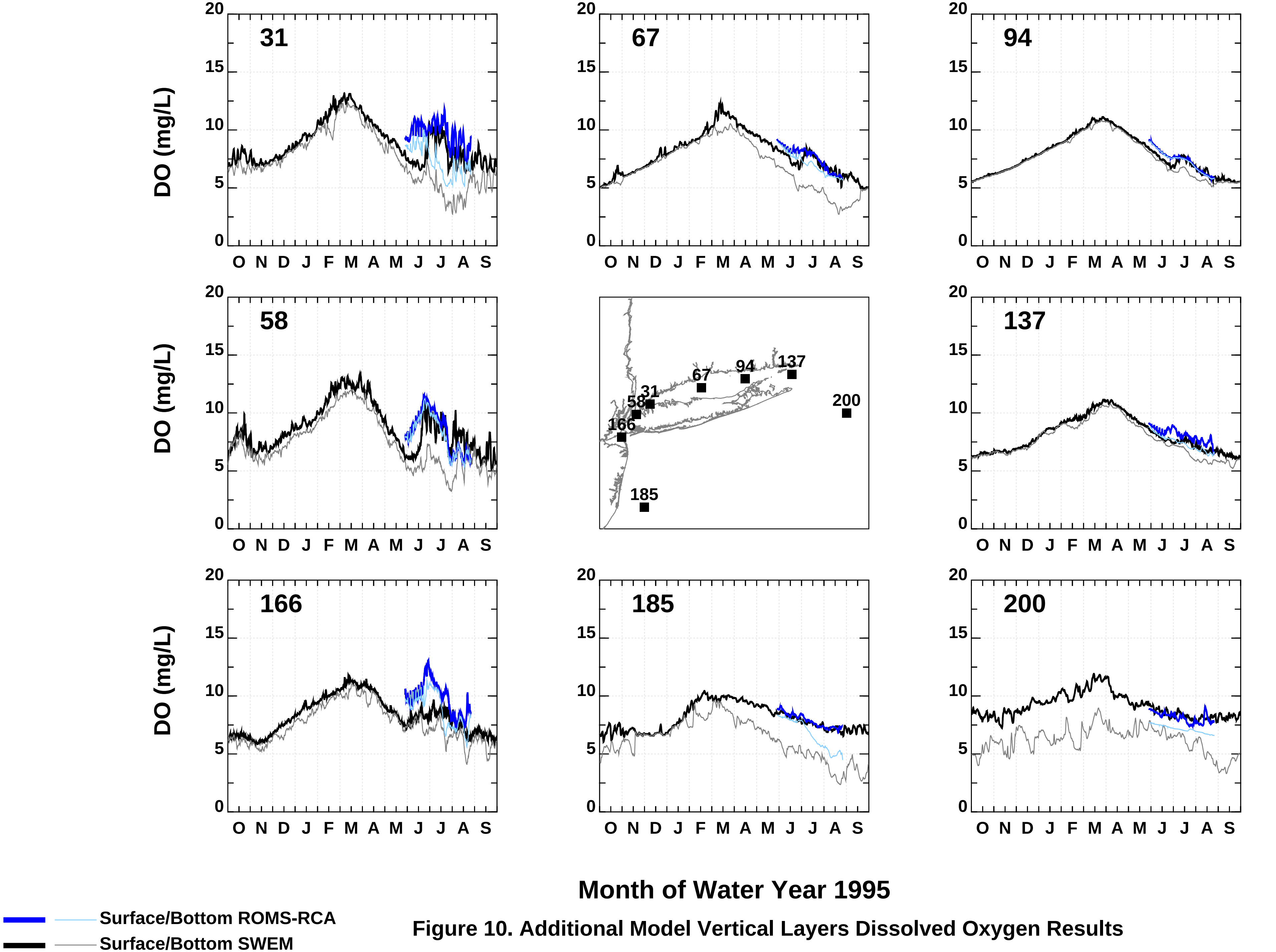


Figure 10. Additional Model Vertical Layers Dissolved Oxygen Results

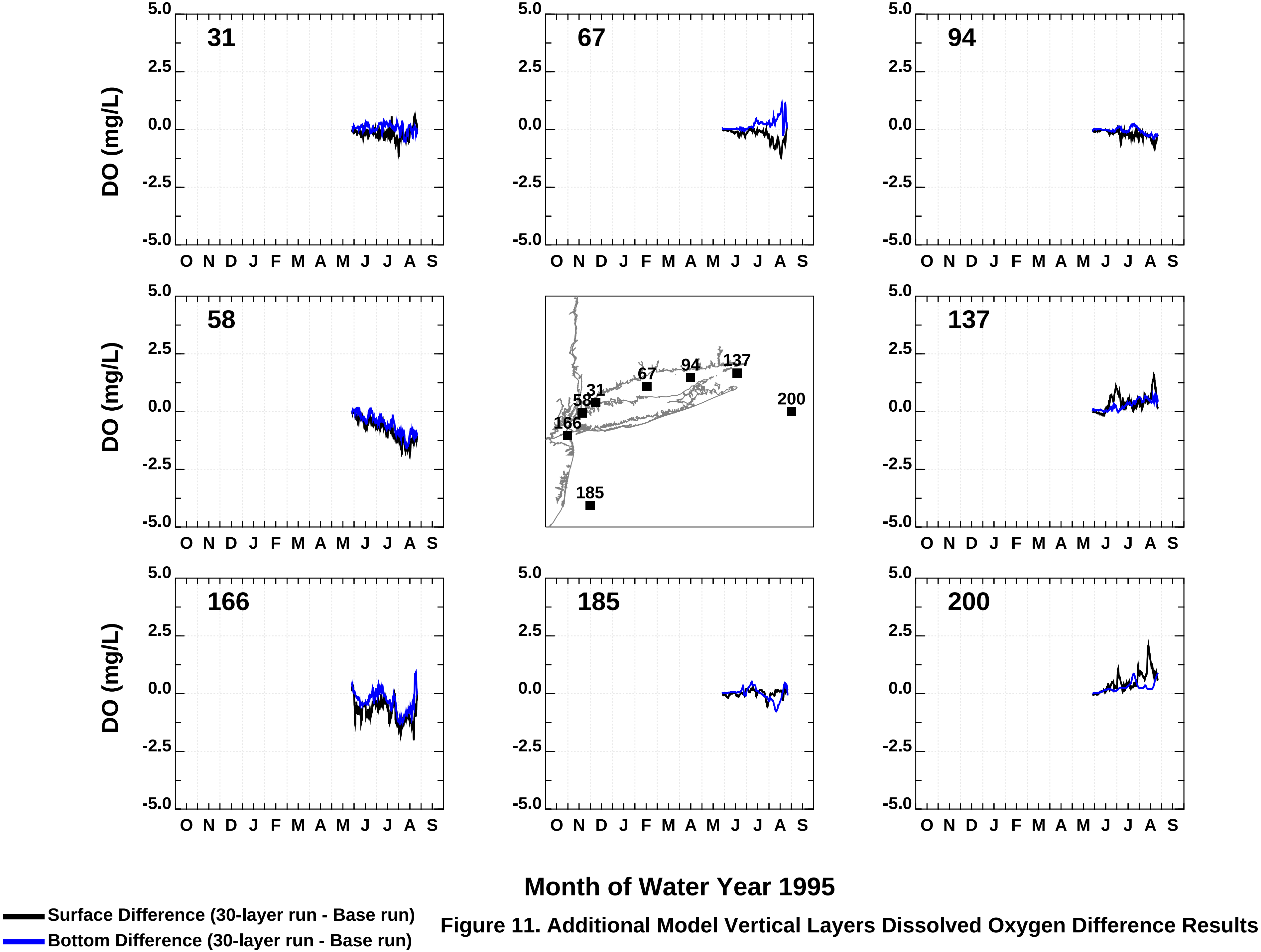


Figure 11. Additional Model Vertical Layers Dissolved Oxygen Difference Results

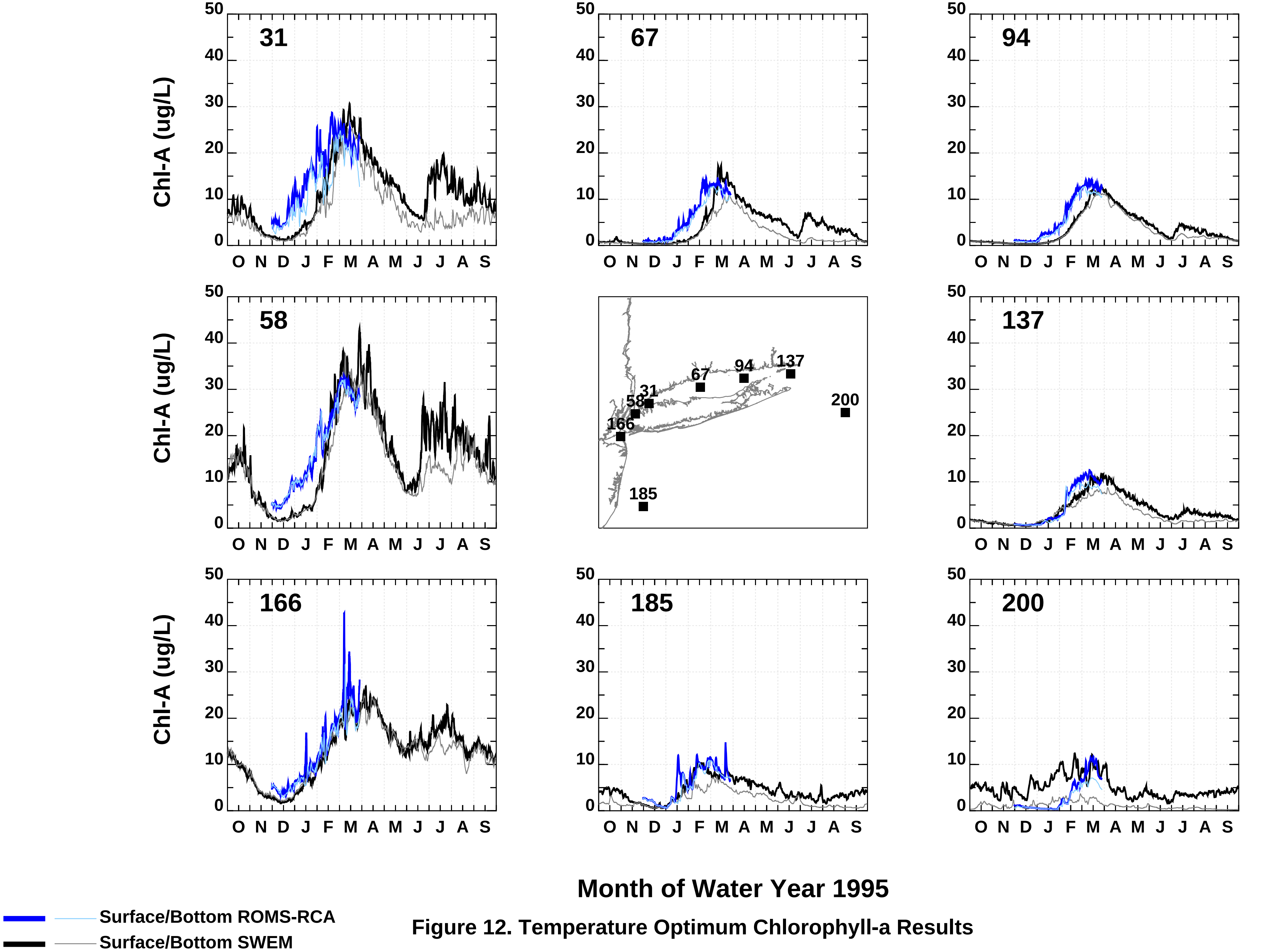


Figure 12. Temperature Optimum Chlorophyll-a Results

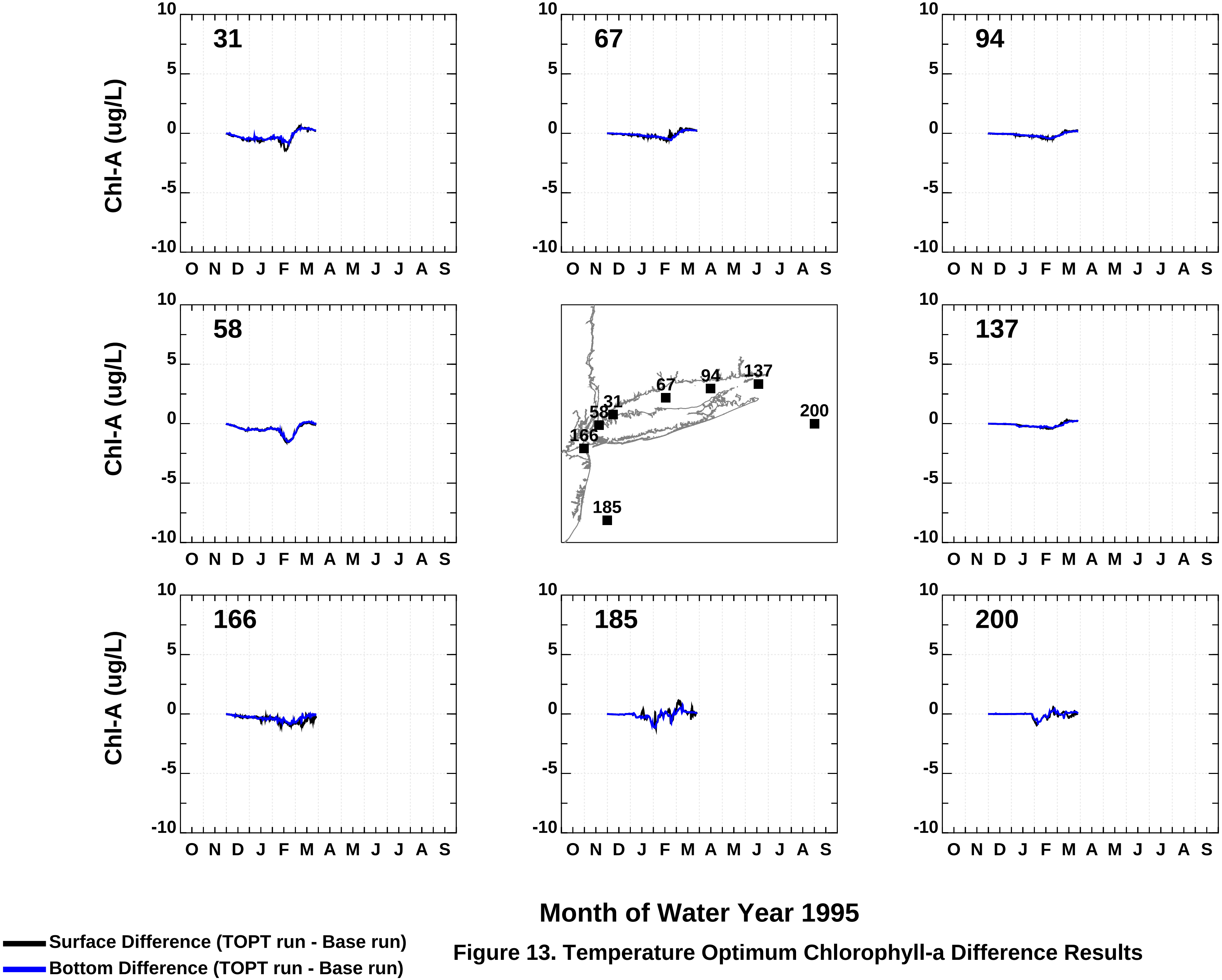


Figure 13. Temperature Optimum Chlorophyll-a Difference Results

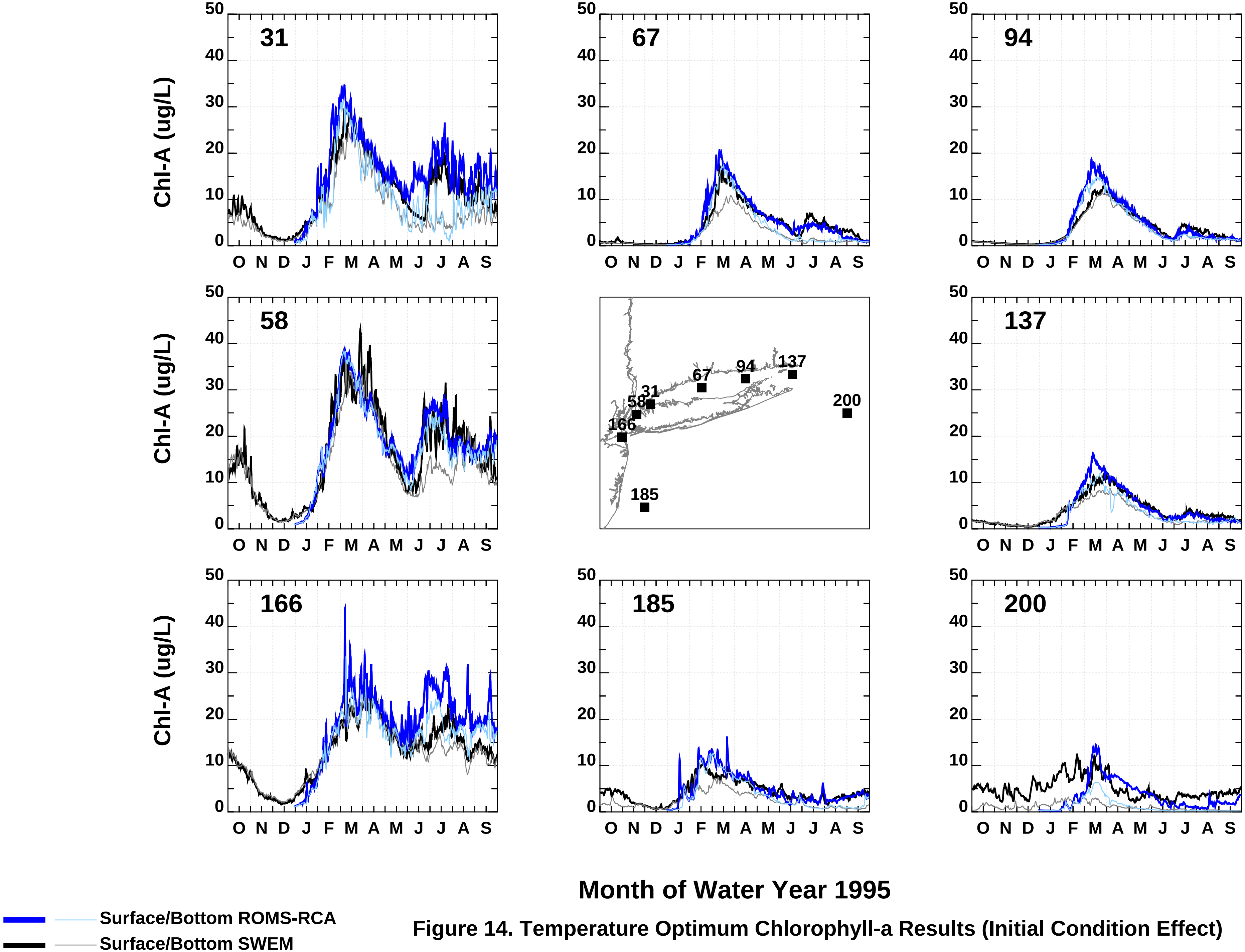


Figure 14. Temperature Optimum Chlorophyll-a Results (Initial Condition Effect)

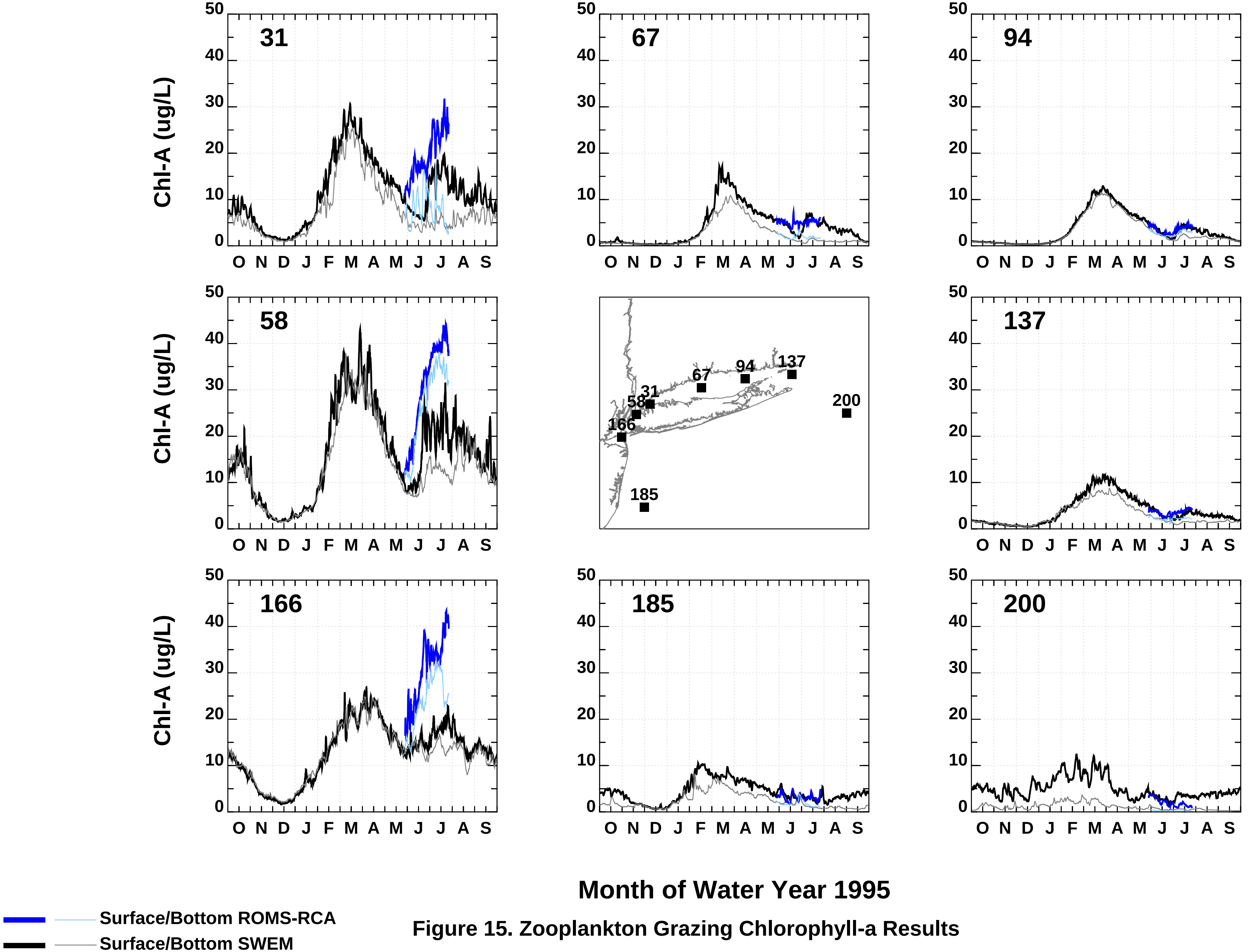


Figure 15. Zooplankton Grazing Chlorophyll-a Results

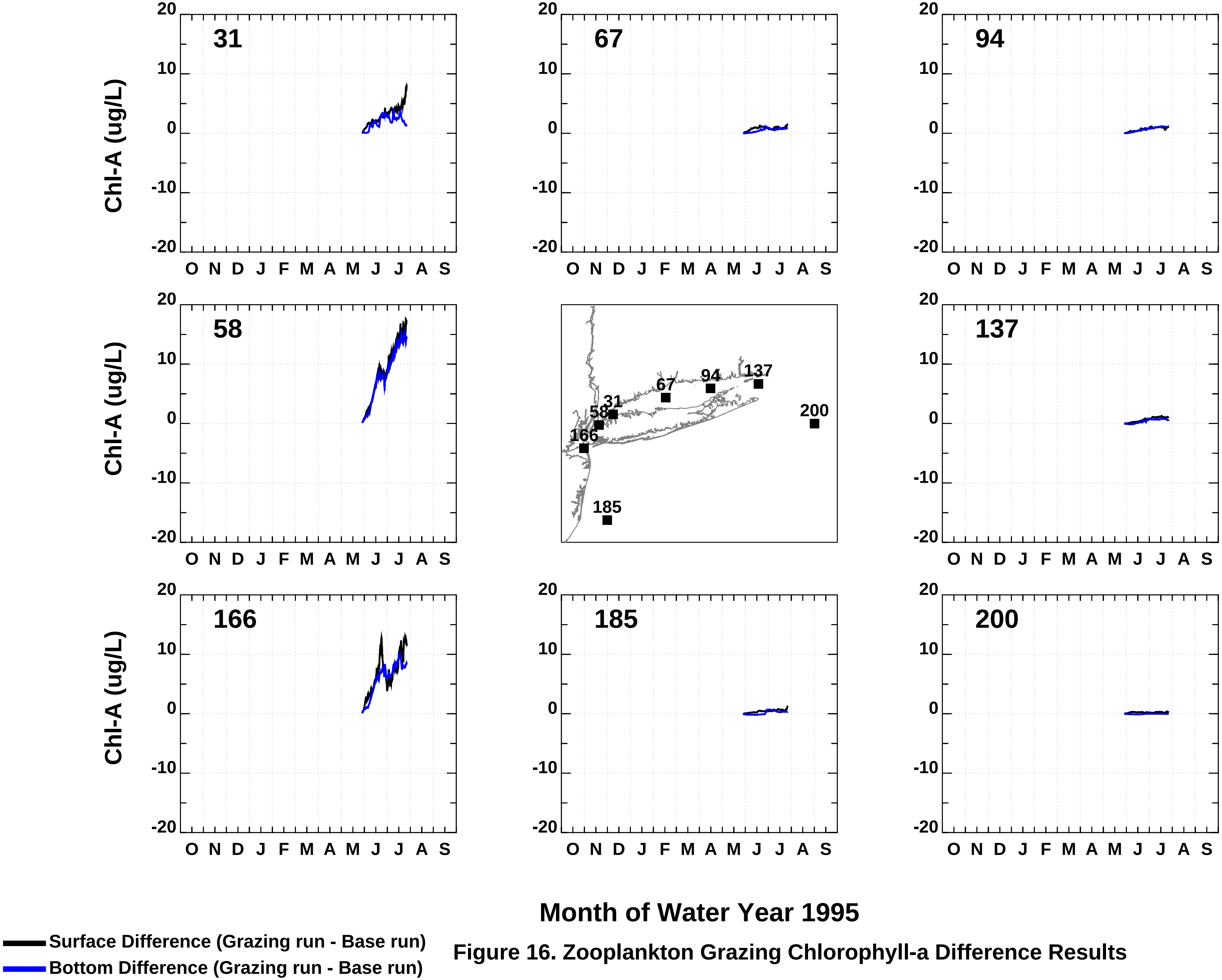
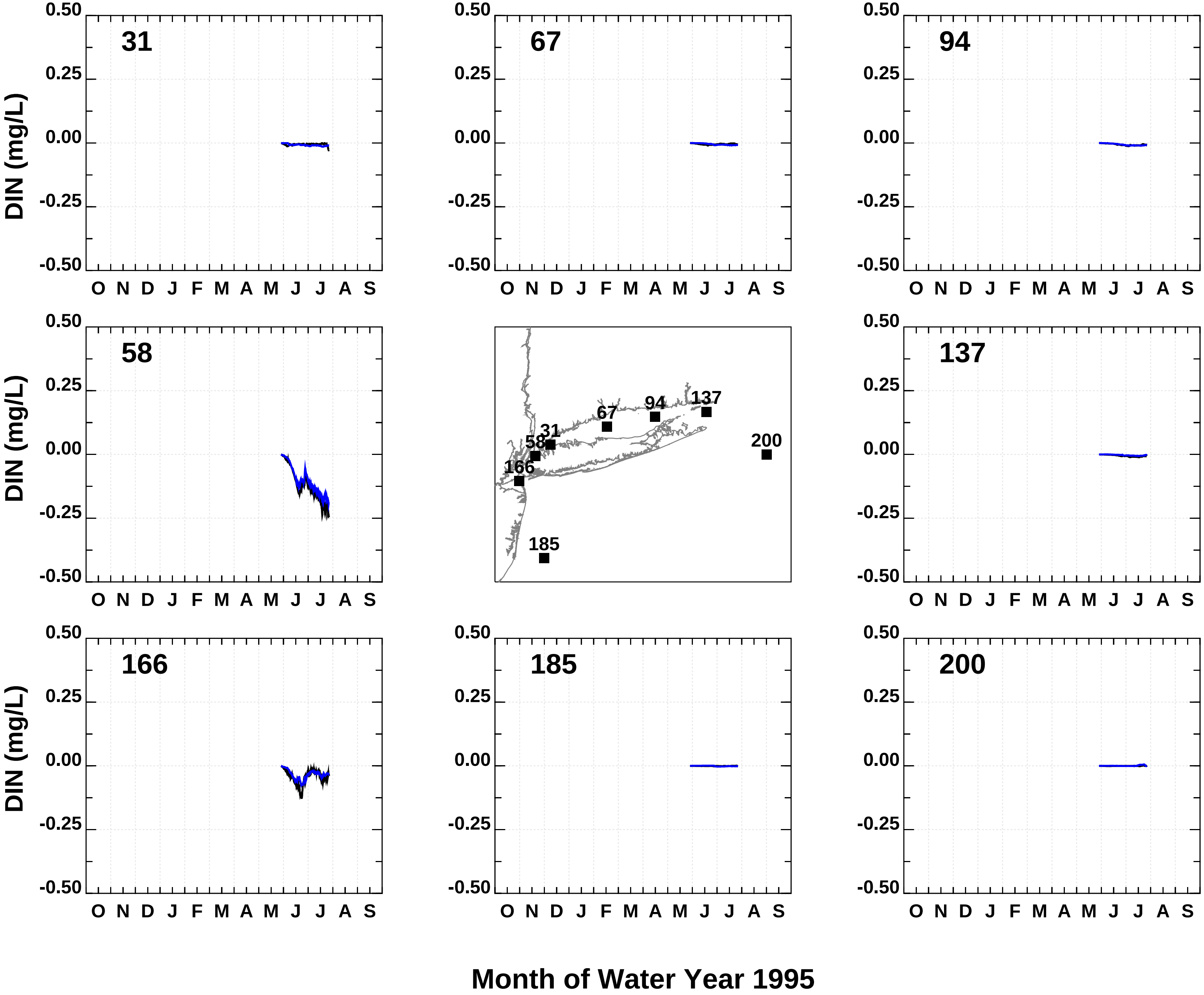


Figure 16. Zooplankton Grazing Chlorophyll-a Difference Results



Surface Difference (Grazing run - Base run)
Bottom Difference (Grazing run - Base run)

Figure 17. Zooplankton Grazing DIN Difference Results

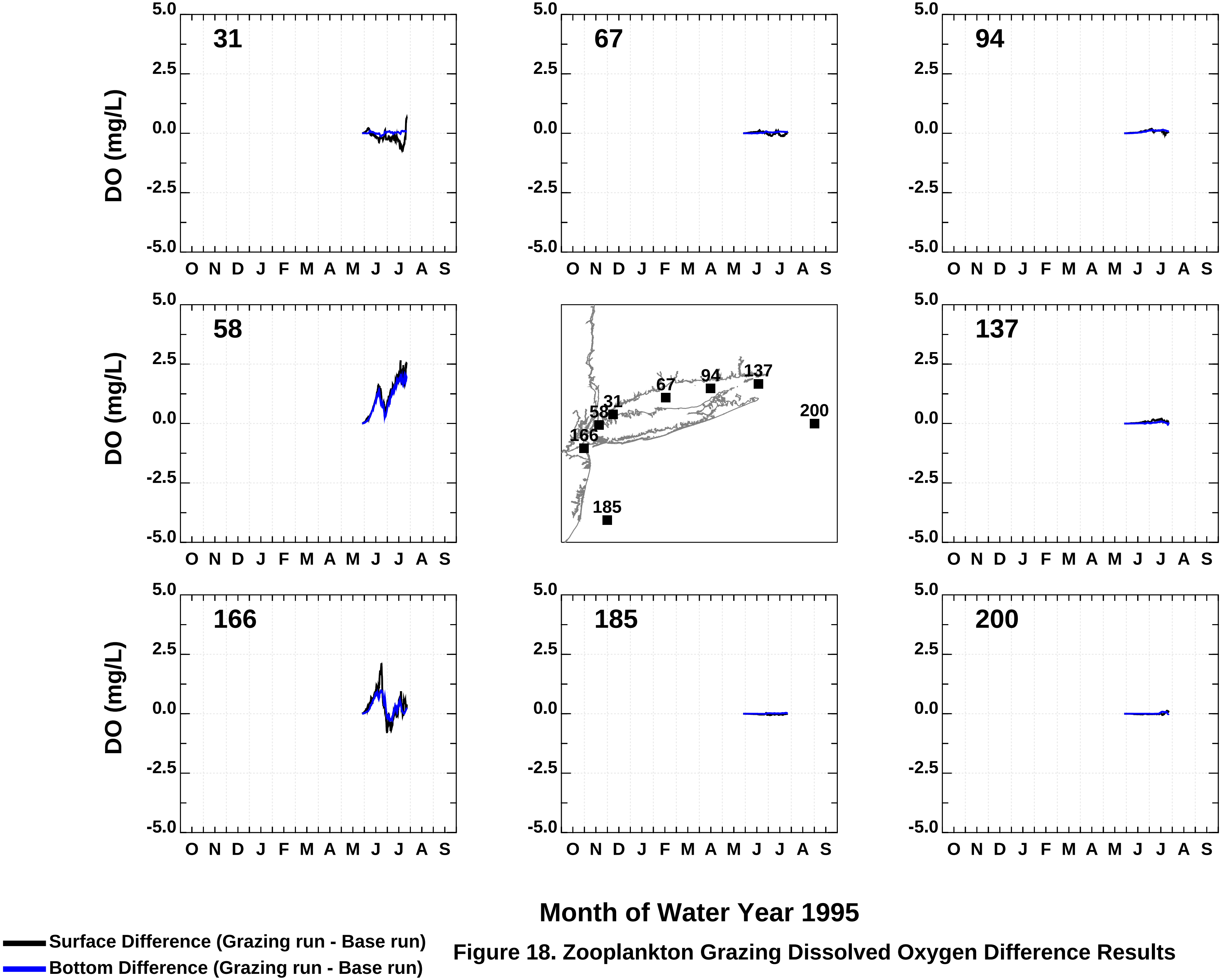


Figure 18. Zooplankton Grazing Dissolved Oxygen Difference Results