

Distributions of Chromophoric Dissolved Organic Matter in New York Harbor

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LONG-TERM GOALS

The long-term goal of the project is to investigate the distributions of chromophoric dissolved organic matter (CDOM) in the New York/New Jersey Harbor and New York Bight system so as to facilitate a deeper understanding of the source and processes that control CDOM distributions in estuarine and coastal waters. CDOM source strengths and photochemical degradation processes were incorporated into a calibrated/validated three dimensional estuarine and coastal ocean forecast circulation model. The model results were compared with high resolution 4-dimensional measurements of physical water properties as well as CDOM data. The detailed distributions of modeled currents, temperatures, salinities, water levels and CDOM were used to help interpret the CDOM data.

OBJECTIVES

The objective was to develop a capability for incorporating CDOM source strengths and chemical processes into the currently operational New York Harbor Observation and Prediction System (NYHOPS, www.stevens.edu/maritimeforecast/). The first year objective was to build CDOM into NYHOPS and conduct simulations of CDOM distributions initially treating CDOM as a conservative tracer on the original NYHOPS model grid. In the second year we updated NYHOPS and its CDOM component to a higher-resolution model grid, updated CDOM sources and strengths in the model based on field observations, and included in the model CDOM photodegradation due to ultraviolet light based on a first-order decay rate measured through laboratory incubation experiments.

APPROACH

NYHOPS is a real-time, web-based estuarine and coastal ocean observing and modeling system for the waters of the New York Harbor region. The NYHOPS modeling system is based on the latest version of ECOMSED, the shallow water version of the Princeton Ocean Model (POM). The NYHOPS implementation of ECOMSED/POM is based on work led by the PI at the Stevens Institute of Technology (SIT) for the New York/New Jersey Harbor and New York Bight system. The spatial extent of the new high-resolution NYHOPS domain incorporates the core area of NY/NJ Harbor as defined by the Harbor Estuary Program and extends beyond to include the Hudson River Estuary, up to the Troy Dam, Delaware Bay, the NJ Atlantic sea shore and bays, all of Long Island Sound, Narragansett Bay, and the New York Bight out to the continental shelf (Figure 1). NYHOPS observations, managed and supported by SIT, consist of shore-based and moored platforms at strategic

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14. ABSTRACT The long-term goal of the project is to investigate the distributions of chromophoric dissolved organic matter (CDOM) in the New York/New Jersey Harbor and New York Bight system so as to facilitate a deeper understanding of the source and processes that control CDOM distributions in estuarine and coastal waters. CDOM source strengths and photochemical degradation processes were incorporated into a calibrated/validated three dimensional estuarine and coastal ocean forecast circulation model. The model results were compared with high resolution 4-dimensional measurements of physical water properties as well as CDOM data. The detailed distributions of modeled currents, temperatures, salinities, water levels and CDOM were used to help interpret the CDOM data.					
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locations inside the harbor and at four sites along the coast of New Jersey, each with in-situ ocean and air-sea interaction measurements. In the second year of the project, the NYHOPS-supportive observation network has been expanded to include NOAA/NOS, USGS, NDBC, C-MAN, and UCONN stations (Figure 1).

In order to enhance the forecast product, the NYHOPS structure was redesigned to make better use of high-resolution inputs, including bathymetry, river forecasts, storm surge forecasts, and meteorological forecasts. To ensure accuracy of the modeling, the new high-resolution NYHOPS was validated against physical observational data from the expanded network of ocean and weather sensors, initially for a calendar year 2004 validation period, and then during the CDOM observing periods.

In order to a) decrease NYHOPS forecast-preparation time and b) allow for an easier, modular, design and further expansion of the CDOM model, the model code used for CDOM was a NYHOPS-coupled RCA code (Raw-Column-Aesop; http://www.hydroqual.com/pdf/RCA_Desc_doc.pdf). This modern water quality code is based on the USEPA WASP model, and has a long history of successful coupling with ECOMSED for water quality studies. CDOM was introduced in the RCA model based on guidance from a University of Massachusetts (UMASS), Boston team that collected CDOM observations in the Harbor. CDOM was simulated initially as a tracer by incorporating the field-estimated CDOM source strengths into NYHOPS. In the second year, along with the updates to the high-resolution model, photodegradation of CDOM due to ultraviolet radiation at the water surface was included in the model code as a 0.168/day first order decay rate applied at the surface layer during daylight hours.

WORK COMPLETED

The work completed includes:

- 1) Ensuring the continuous flow of NYHOPS-supporting real-time or near-real-time (collected 0-5hrs in the past) data from multiple agencies: a) 13 SIT-maintained sites, including 2 HR-radar systems located within the NY harbor, b) 2 Rutgers-maintained HF-Radar systems, c) 2 C-MAN stations, d) 1 NOS ADCP, e) 5 NDBC stations, f) 33 NOS stations, g) 4 UCONN-maintained stations, h) 40 USGS stations, i) 6 NY Met stations providing overland observations of local meteorological conditions, j) Vessel-based conductivity and temperature sensors.
- 2) Comparisons of these observations with the NYHOPS forecast results at many of these sites, updated and displayed hourly – along with statistical measures of model performance – on the NYHOPS website.
- 3) Incorporation of river inflows into the high-resolution forecast system data stream using real time data and Advanced Hydrologic Prediction Service forecasts.
- 4) Development of an off-line capability to simulate passive constituents using RCA and transport fields from the NYHOPS high-resolution forecast output stream.
- 5) Configured system to accept source strength inputs of CDOM and conducted simulations to ensure that the system is working properly with CDOM as a conservative tracer.

- 6) Furthermore, CDOM component strengths are also independently simulated in parallel to facilitate component analysis.
- 7) Incorporated preliminary estimates of CDOM source strengths to six end members based on the UMASS-Boston team's recommendations.
- 8) Configured system to accept photodegradation kinetics for CDOM based on incubation experiments.
- 9) Incorporated the CDOM model into the NYHOPS forecast website for use by the data-collecting UMASS-Boston team
- 10) Adjusted the preliminary source strengths as suggested by field observations.

RESULTS

An RCA-based NYHOPS CDOM module was developed to execute in conjunction with daily NYHOPS hydro/waves forecast runs so that transport output from ECOMSED/POM is directly linked to the module. The two models share the same numerical grid structure and underlying numerical solution techniques. To ensure that the two models communicate correctly a "10s" test was conducted. The NYHOPS submodel was initialized with 10 (tracer units) everywhere; all inflows were assigned that same concentration. The model was run for a 30 period using January 2004 river inflows. Model concentrations never deviated from the expected 10 units.

The original NYHOPS forecast system included 25 simplified river systems based on 27 real time USGS gages. Based on newly available USGS real time stations, and work completed recently (Georgas, 2006), the high-resolution NYHOPS system includes 93 river systems, with river outlets spanning seven coastal states (NY, NJ, CT, RI, DE, PA, MA), based on 74 real time USGS gages. Figure 2 shows the contributing simulated river watersheds. For example, the direct tributary outlets to the Hudson River system north of the Battery, NY, including the river itself north of Troy, NY, have now been increased to 20 from the original 14. Similarly, the direct tributary outlets to Raritan Bay, NJ, have increased to 11 from the original 4. Rivers and outlets in the states of RI, DE, PA, and MA are all new additions as well. The detailed representation of river systems increased the ability of identifying and tracking CDOM sources in the area of interest.

Similar to the higher resolution characterization of individual watershed non-point sources described above, the original network of water treatment plants and other water discharging industrial facilities was expanded to include 280 dischargers, 39 of which are thermal dischargers, the remaining being freshwater-discharging treatment plants, characterized as major dischargers by USEPA (Figure 3). Mean discharge from all plants is estimated to equal approximately 1,000 m³/s, which is of the same order to the estimated long-term-average flow of the Connecticut (~560m³/s) and Delaware (~400m³/s) rivers combined. 80% of that flow is due to re-circulating flow within thermal plants, the remaining 20% (~200m³/s) being freshwater flow added to the system mainly by public sewage treatment plants. The latter value is approximately equal to 1/3 of the mean freshwater flow reaching the southern tip of Manhattan due to the Hudson River and all its tributaries. Obviously, the detailed inclusion of these freshwater systems is of primary importance to any high-resolution forecasting system of the NY/NJ Harbor Estuary and its coastal ocean, both in terms of salinity and temperature prediction, but also in terms of currents and pollutant dispersion predictions due to the strong estuarine

(density-driven) circulation. Moreover, these 280 independent sources may be CDOM sources as well, and their inclusion allows for simulation of their effect on CDOM distributions.

The key tributaries for this study are the Hackensack, Passaic, Hudson, and Raritan rivers (Figure 4). CDOM end members were provided for these tributaries by R. F. Chen, G. B. Gardner and Y. Tian of UMASS, Boston who are working on a very closely linked ONR effort. Two point source end members were also investigated: The Bergen County water treatment plant discharging in the Hackensack River and the Port Richmond water treatment plant discharging in the Kill van Kull that, along with Arthur Kill to its south west, connects Raritan and Newark Bays (Figure 4).

An example of data-driven hypotheses that can be tested through the use of the model is the inclusion of the Bergen County facility as a CDOM source for the Hackensack River. This was hypothesized based on data collected by the Boston team during October 2006. Figures 5 through 7 explain the impact of that treatment plant to local CDOM concentrations along the Hackensack River. Of particular significance is the fact that the Hackensack river watershed itself contributes, on the average, a smaller freshwater input than the mean freshwater input coming from the treatment plant: The median flow of the Hackensack river is around 1.8m³/s, while the median flow of the treatment plant is around 3.6m³/s, roughly double.

Figures 8 and 9 show the flows of the Passaic and Hackensack Rivers, respectively, at the point they enter the model grid, based on the available USGS gage data for calendar year 2004. Note that the Passaic River has approximately an order of magnitude greater flow than the Hackensack. In fact, the model shows that CDOM from the larger Passaic River has an impact on the Hackensack River proper too. This notion has been introduced in the component analysis of Figure 7, where the Hackensack River and Bergen County plant CDOM loads sit on top of a Passaic-river-related background CDOM concentration. It is also seen in Figures 10 and 11 which show tracer concentrations following a continuous, uniform tracer release from all rivers in the NYHOPS model. During ebb tide in the early morning of January 2nd, 2004 (Figure 4), the Passaic River plume is visibly entering Newark Bay, while tracer in the smaller Hackensack, is barely measured for most of the visible span of that Newark Bay tributary. Six hours later (Figure 5), the flooding tide brings a considerable load from the Passaic River plume into the Hackensack River through its Newark Bay outlet, while the Hackensack plume itself moves to the North. This was an early confirmation of the hypothesis that constituents originating in the Passaic River can easily travel up the Hackensack River.

Compared to the significance of the Bergen County facility as a potential source of CDOM, the alleged significance of a second water treatment plant investigated by the NYHOPS CDOM model appears to be considerably smaller. The NYC-DEP Port Richmond Plant outfall in the Kill Van Kull (Figure 3) is predicted to have an almost negligible effect on the local distribution of CDOM, in spite of its higher concentration (200 QSU). This is hypothesized to be due to a smaller mean flow (1.5m³/s), and, more importantly, rigorous mixing and dispersion in the area of the outfall (Figure 12).

IMPACT/APPLICATIONS

The work presented here contributes significantly to the understanding of the mechanisms by which CDOM enters and disperses/accumulates in the nearshore marine environment. It provides a major step forward to the incorporation of CDOM into an advanced, integrated system of oceanographic and meteorological sensors and operational littoral-ocean forecasting models. The model results of CDOM distributions provide a means of estimating and predicting the ecological dynamics of the coastal zone.

The operational model has shown that it can evaluate observation-based hypotheses of source strengths, and can continue to do so, testing, for example, an alleged CDOM load from the Meadowlands salt marshes (Figure 6). It can also test the significance of photodegradation to CDOM distributions. Hindcasting of observation periods can help fine-tune such scientific findings. By assimilating satellite remote sensing ocean color data from programs like CZCS, TOCS, SeaWiFS, and IKONOS, important ecological events may be forecasted. A recent study shows that chlorophyll concentrations, combined absorption of detrital and dissolved material (CDOM) at 443nm, and backscattering coefficient at 443 nm (a measure of the total suspended matter) can be retrieved from SeaWiFS data (Li et al., submitted).

The observational network and modeling system are parts of the integrated, sustained ocean observing system envisioned by the National Oceanographic Partnership Program (NOPP), under the OCEAN.US office, and the Integrated Ocean Observing System (IOOS). The PI has been an active participant in the Mid-Atlantic Coastal Ocean Observing Regional Association (MACOORA).

RELATED PROJECTS

This effort is a companion study to the ONR funded study of R. F. Chen, G. Bb Gardner and Y. Tian of the University of Massachusetts, Boston. Their study, "Predicting Chromophoric Dissolved Organic Matter Distributions in Coastal Waters" will provide the data upon which the analysis of this proposed is based.

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PUBLICATIONS/PRESENTATIONS

N. Georgas, 2006. *Using real time USGS river gages to simulate fluvial contributions to the high-resolution New York Harbor Observation and Prediction system*. Stevens Institute of Technology.

G. B. Gardner, R. F. Chen, A. F. Blumberg, N. Georgas, W. Huang, and F. Peri. *Measurement and Modeling of Chromophoric Dissolved Organic Matter in an Urban Estuary*. Presented at the American Society of Limnology and Oceanography (ASLO) 2007 Aquatic Sciences Meeting. February 4-9, 2007. Santa Fe, New Mexico.

HONORS/AWARDS/PRIZES

Alan F. Blumberg, Stevens Institute of Technology, Elected Fellow, American Society of Civil Engineering.

Alan F. Blumberg, Stevens Institute of Technology, Appointed to the Science Advisory Board (SAB), U.S. Environmental Protection Agency.

Nickitas Georgas, Stevens Institute of Technology, 2006 American Shore and Beach Preservation Association Educational Award.

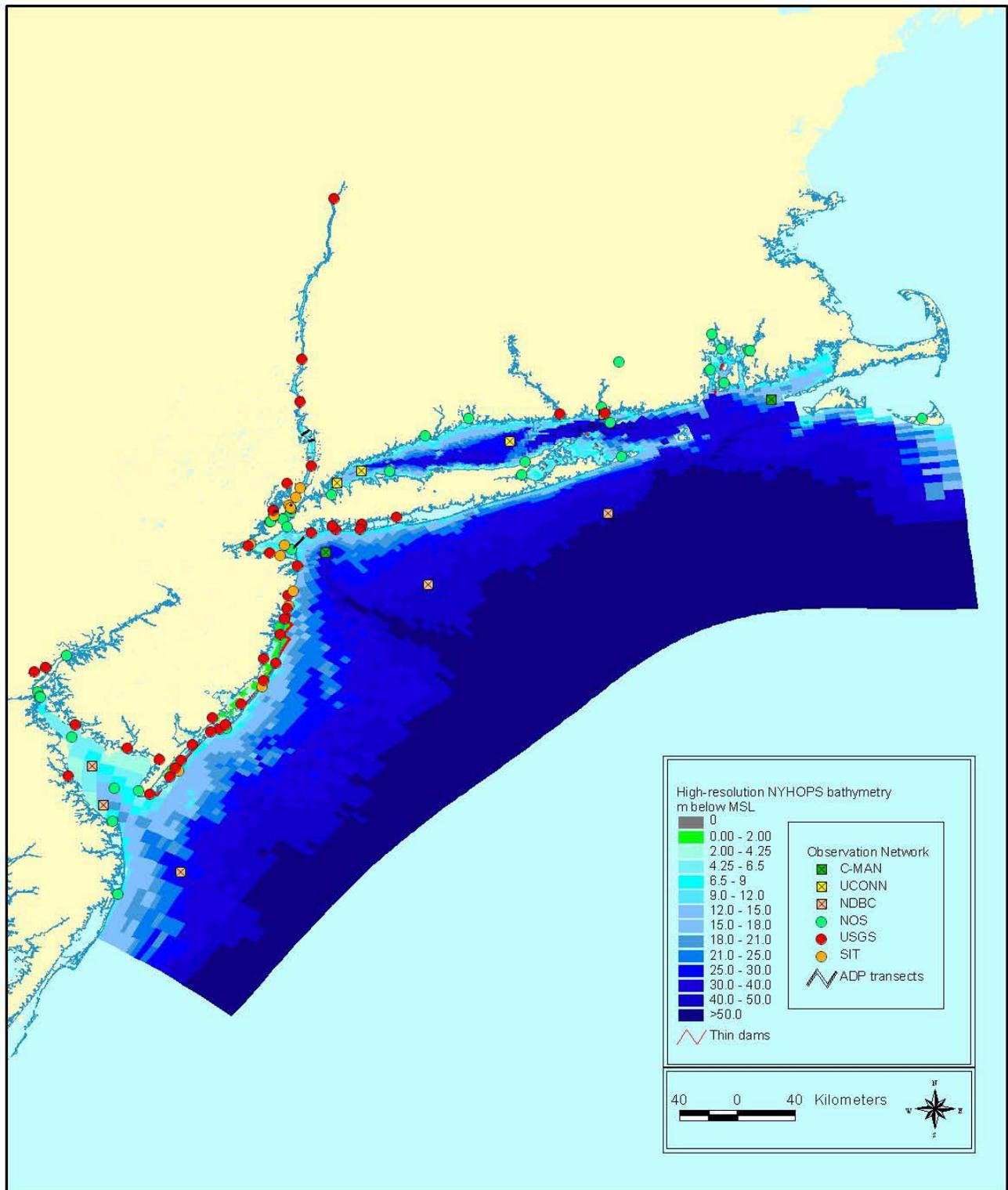


Figure 1. NYHOPS-supportive observation network. Year 2007 expansion to include data collected by agencies other than Stevens Institute of Technology. Station locations are superimposed on the updated (since Jan 17th 2007) high-resolution NYHOPS model that includes CDOM sources and kinetics.

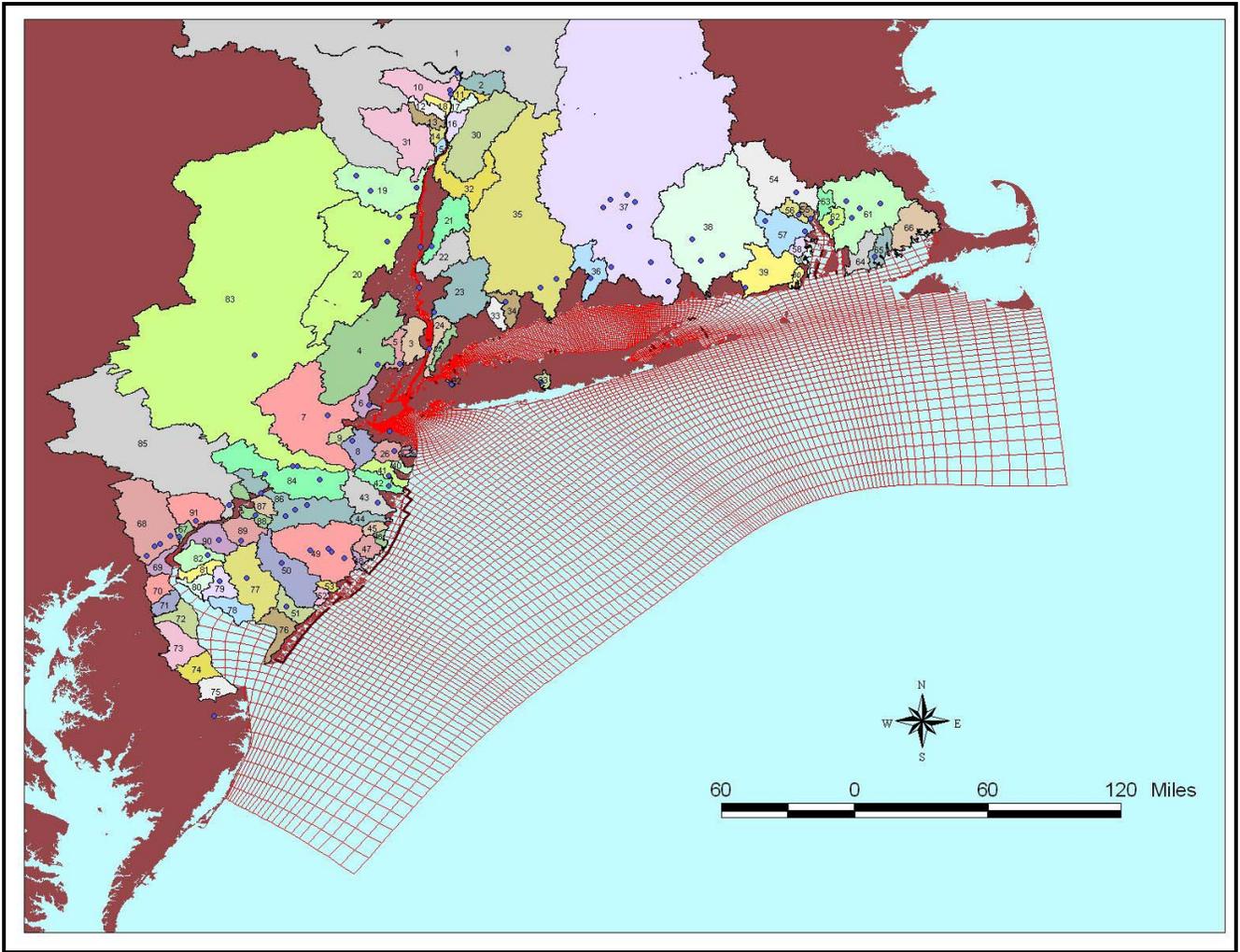


Figure 2. Individual rivers and streams in NYHOPS (colored watershed polygons), with locations of applicable real time gages (blue dots). The variable, curvilinear, high-resolution NYHOPS grid cells are also delineated with red.

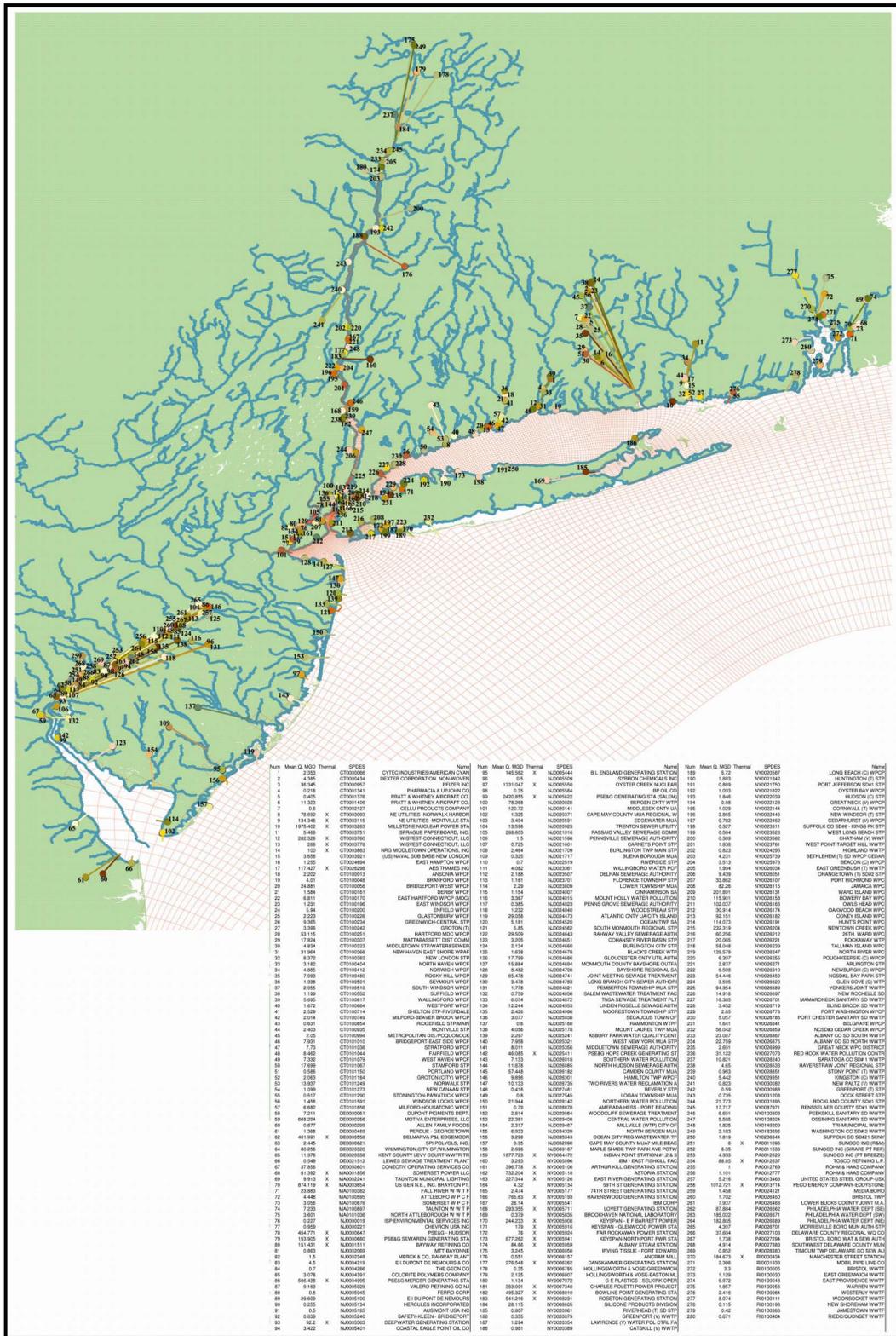


Figure 3. The new high-resolution HIGHRES model includes the ability to simulate 280 independent point sources of CDOM shown as dots in this figure. Lines connect location of actual and simulated outfalls, due to limitations on the extent of the model grid. The embedded table lists all 280 sources by name and mean discharge.



Figure 4. Non-point source (river, in red) and point-source (treatment plant, in green) CDOM end-point strengths, in quantitative salinity units (QSU), as simulated in the Stevens IT NYHOPS model, based on observation-derived guidance by the Umass Boston team.

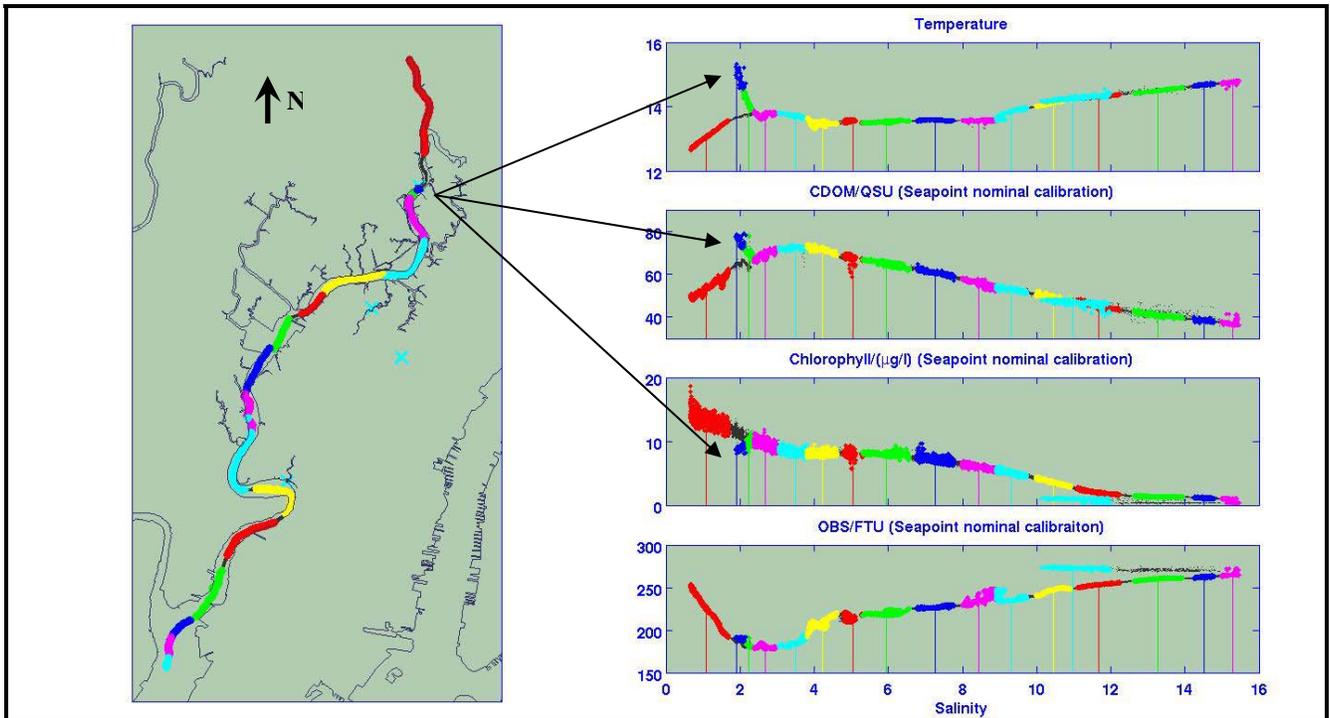


Figure 5. Results of the October 2006 CDOM survey of the Hackensack River (map on the left). The panels to the right show different parameters against salinity, the latter typically increasing from north to south, as Hackensack River freshwater dilutes Newark Bay salt water. Colors of data shown correspond to colors on the transect map. Panels from top to bottom: a) Temperature ($^{\circ}\text{C}$) vs. Salinity (psu) (T/S-diagram), b) CDOM (QSU) vs. Salinity (psu), c) Chlorophyll ($\mu\text{g/L}$) vs. Salinity (psu), and d) Optical Back Scatter (FTU) vs. Salinity. The survey was conducted by a UMASS Boston team, guided by the NYHOPS CDOM forecast model. The time of the survey coincided with the end of the ebb tide, and reached the northern end of the transect around low water. The team towed an ECO Mini-shuttle, side-scan sonar, and ADCP along the Hackensack River, and took surface-leaving radiance measurements underway from a 25 ft research vessel. Note the apparent effect of the Bergen County water treatment plant on CDOM concentrations (black arrows). A local maximum in CDOM and water temperature and a local minimum in chlorophyll are observed around the outfall location. Treatment plant effluent is usually at a higher than ambient temperature due to the biological processes involved in the treatment of sewage, hence the local rise in temperature observed. The local rise in CDOM cannot be explained by a local phytoplankton bloom, as chlorophyll concentrations were actually lower around the outfall.

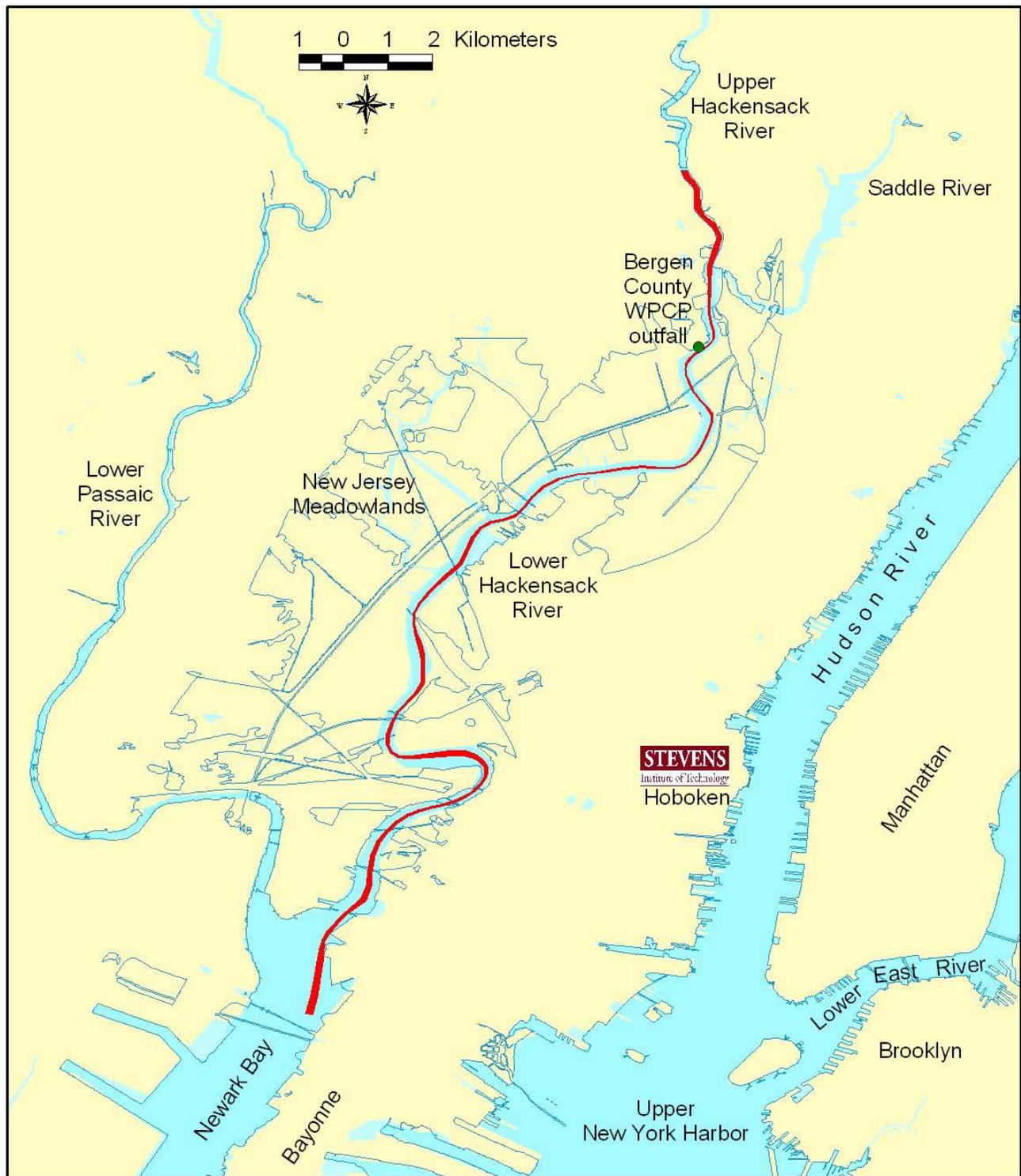


Figure 6. Hackensack River and vicinity. Figure shows the Hackensack river, and, in red, the model transect used to compare simulation results (shown on Figure 7) with Mini-shuttle observations collected by the UMASS, Boston research team. The outfall of the Bergen County Water Pollution Control Plant is also shown (as a green dot). The Plant was estimated to be a source of CDOM in the river.

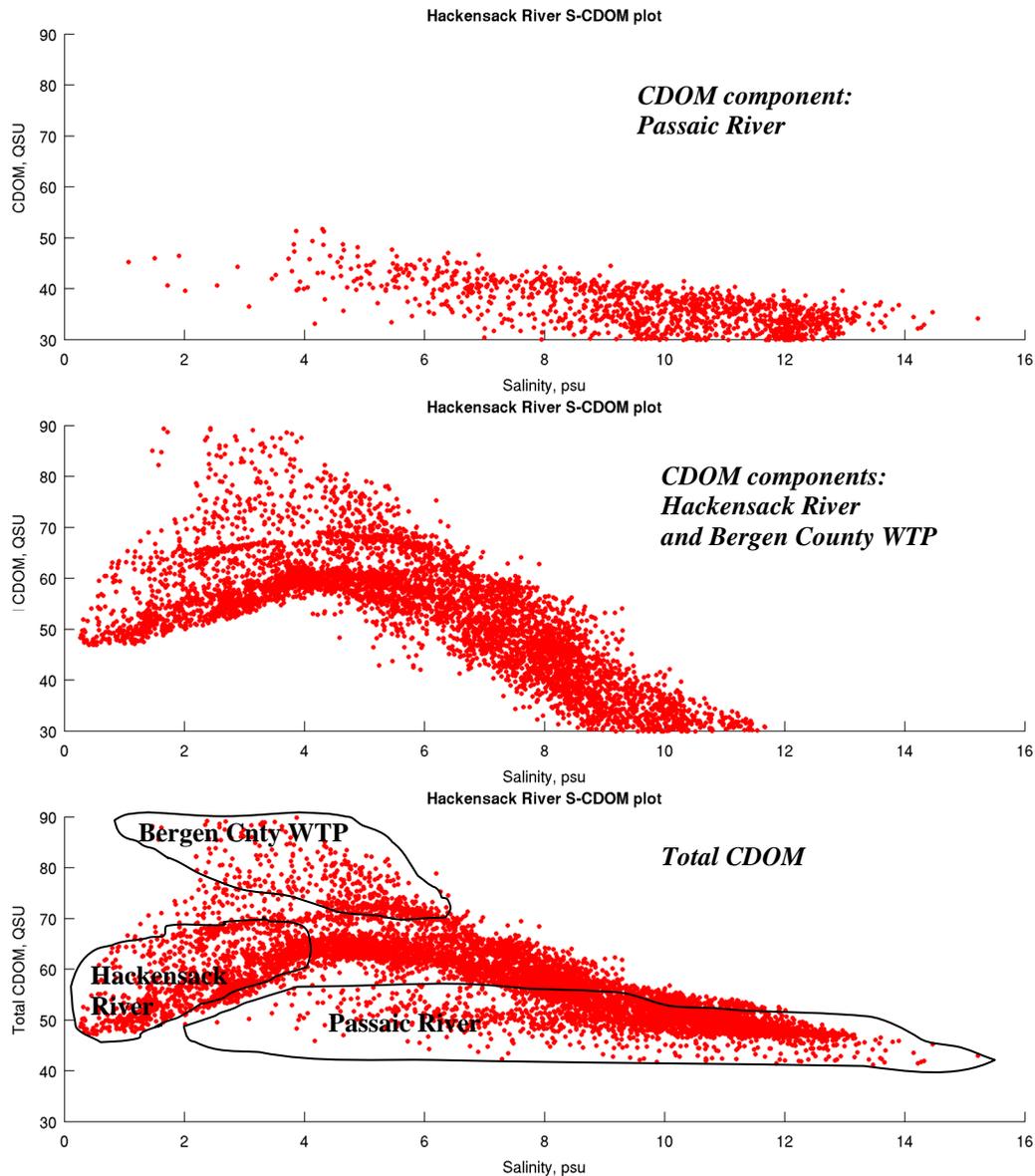


Figure 7. Component analysis of the high-resolution NYHOPS CDOM simulations for 24-26 March 2007, after the RCA CDOM module was configured to include the apparent sources based on the results of the October 2006 Hackensack river survey. Model results are taken from the model cells of the Hackensack river transect shown in Figure 6, which largely coincides with the transect the October 2006 observations were collected along shown in Figure 5 (left panel). The X-and-Y-axes scales of the panels have been set to equal the scales of the S-CDOM observations plot (2nd plot from the top right in Figure 5). Top panel: Source is the Passaic River alone, with a nominal end-member concentration of 80 QSU. Center panel: Sources are the Hackensack River, at 41 QSU, and the Bergen County water treatment facility at 111 QSU. Bottom panel: Total CDOM along the Hackensack transect based on all investigated sources shown on Figure 4. The last panel shows a good correspondence of the model with the observed data. The significant scatter of the data is due to tidal and meteorological influences within the three day period.

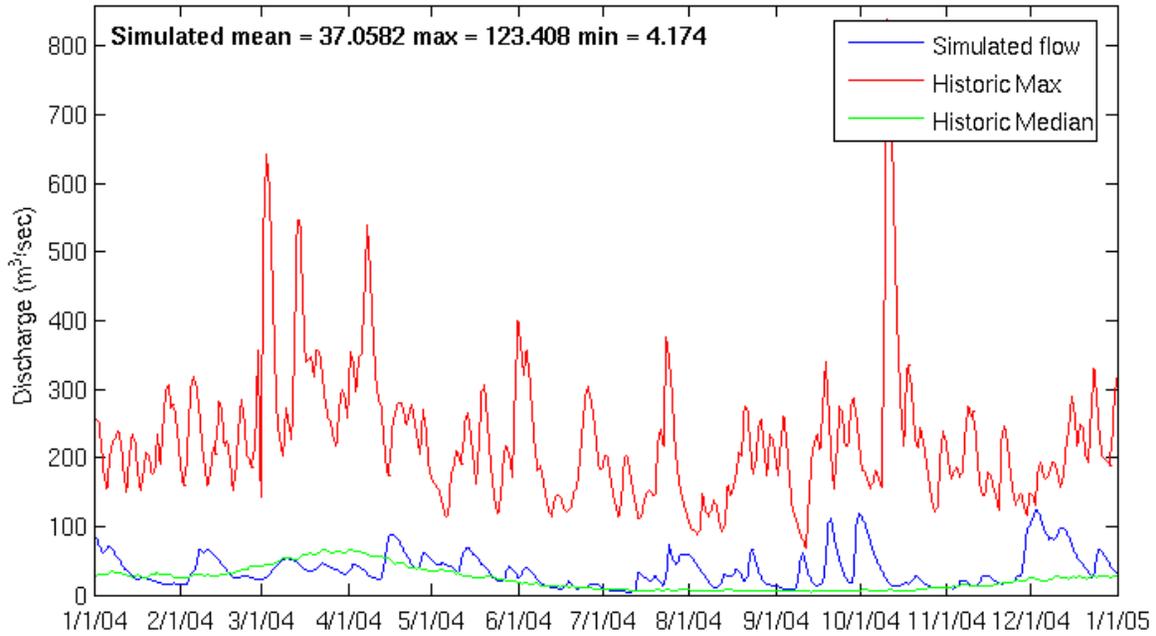


Figure 8. Passaic River Inflow at Dundee Dam, calendar year 2004.

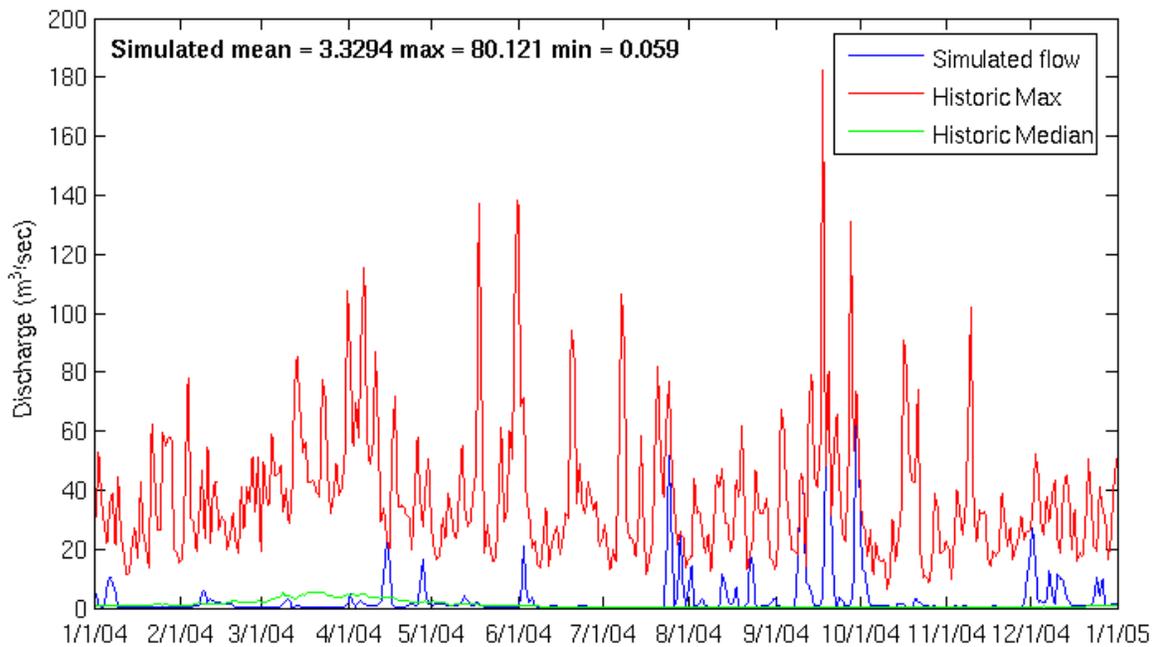


Figure 9. Hackensack River Inflow below Oradell Dam at Foschini Memorial Park for 2004.

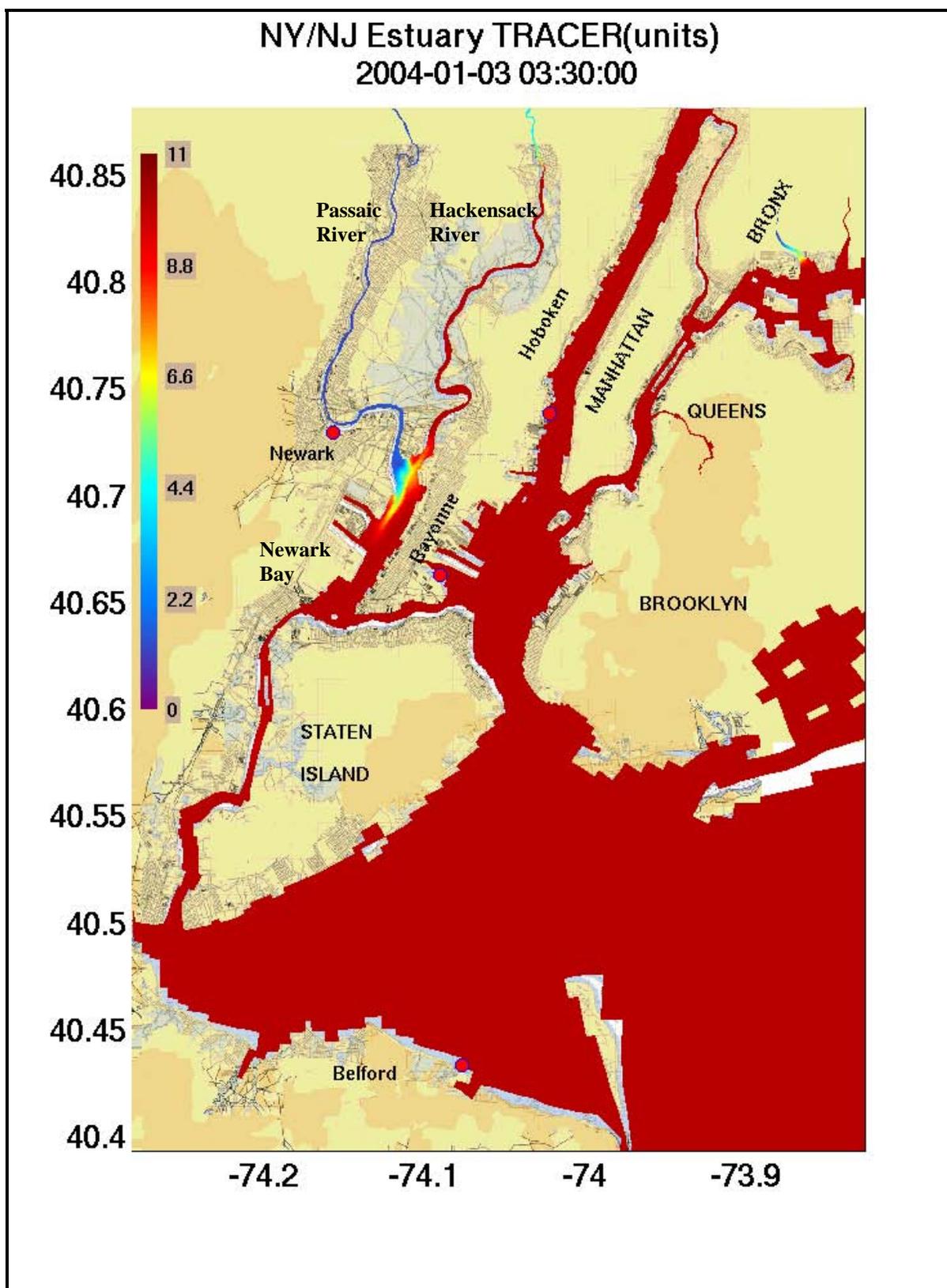


Figure 10. A tracer release from the river systems in the NY/NJ Harbor estuary. Ebb tide.

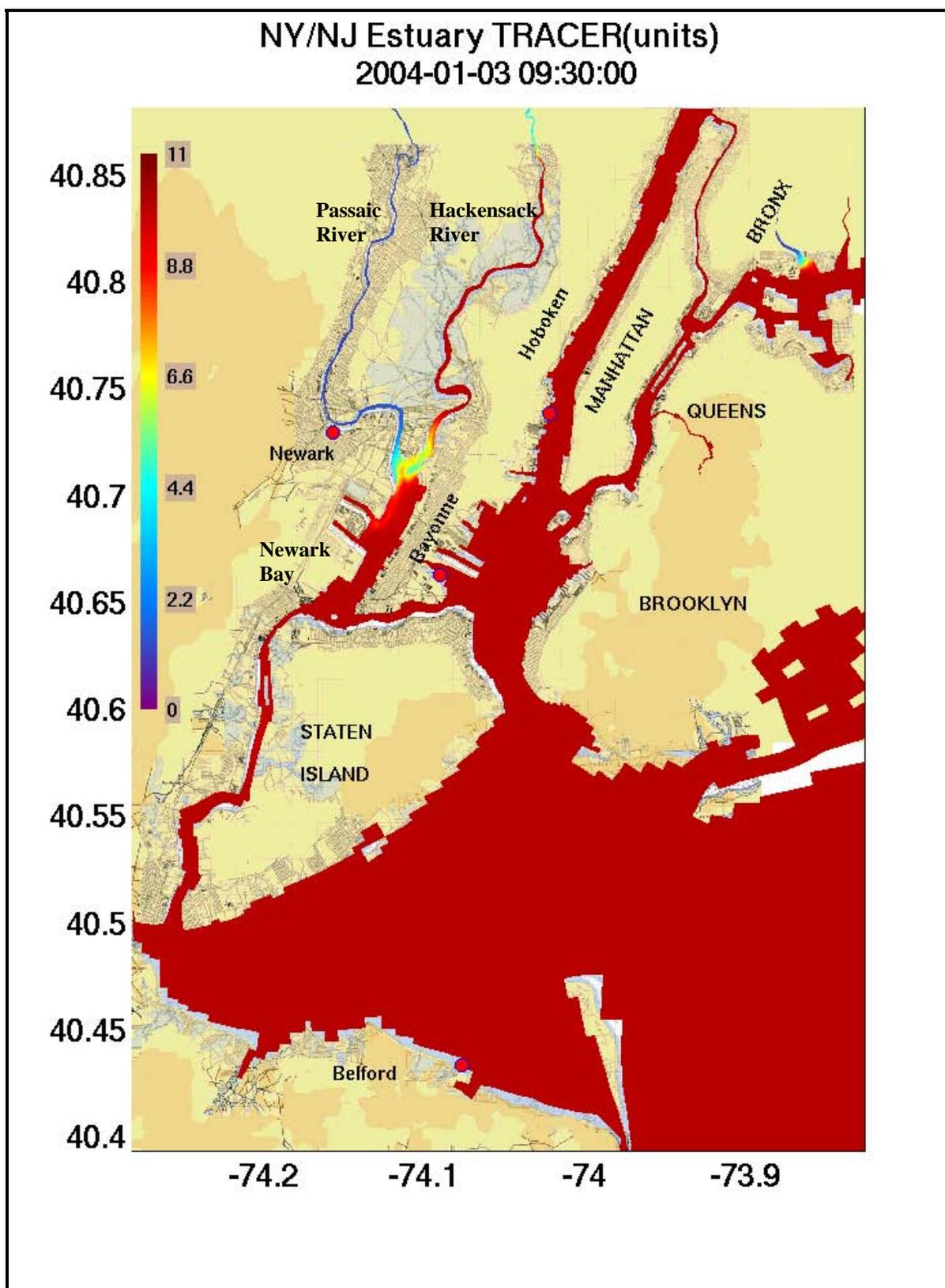


Figure 11. A tracer release from the river systems in the NY/NJ Harbor estuary. Flood tide.

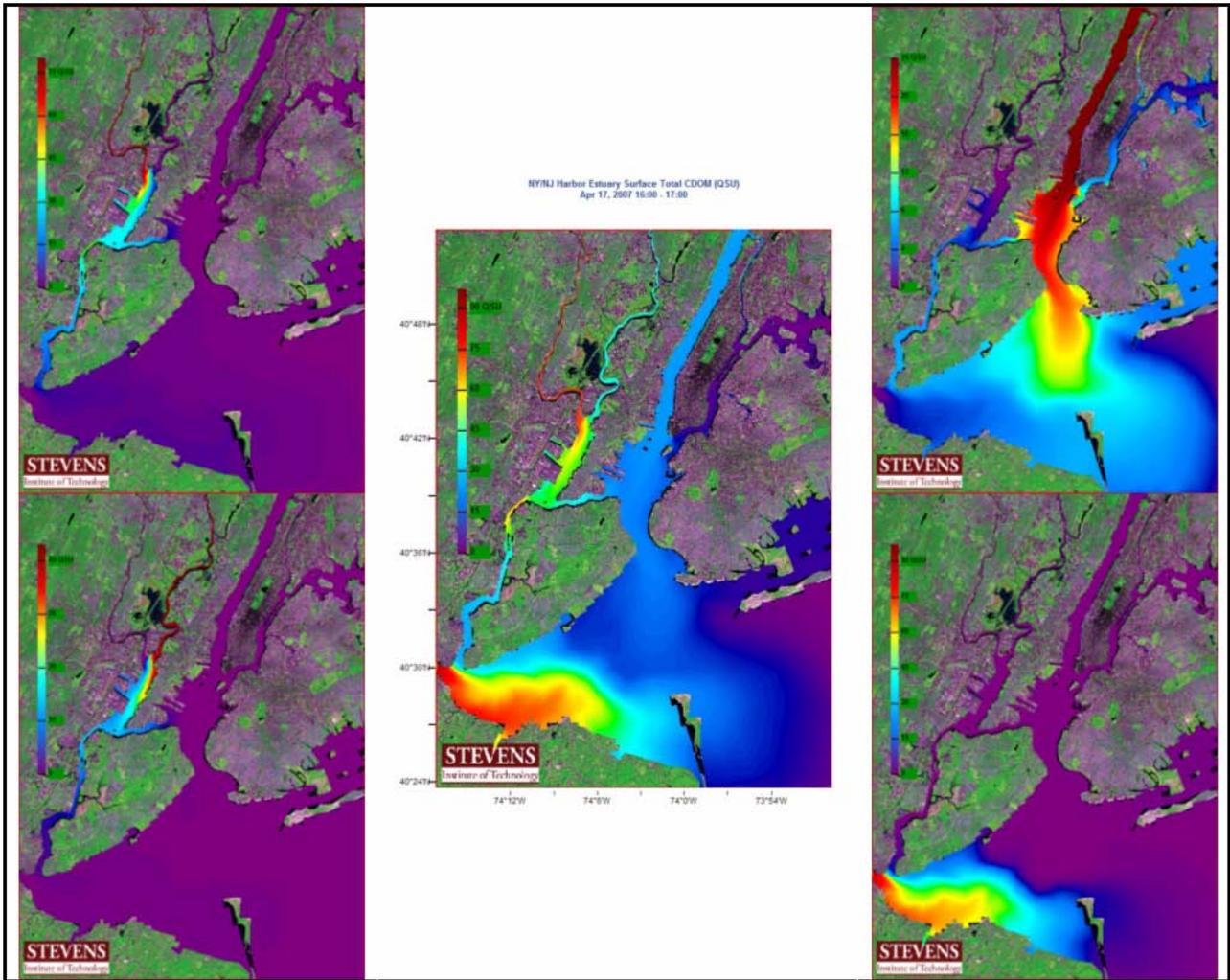


Figure 12. Screen captures of high resolution NYHOPS-predicted CDOM for April 17, 2007 16:30 ET. This date was one of major flooding all along northern New Jersey due to very intense and long-lasting rainfall. The various end members (clockwise from top left, Passaic River, Hudson River, Raritan River, and Hackensack River including the Bergen County water treatment plant), combine their strengths to create the central image which depicts the predicted CDOM concentration in the surface waters of the NY/NJ Harbor Estuary. Due to record-breaking river flows, maximum concentrations in the receiving waters equaled the end member strengths of Figure 4. Note the different scales in the end member color maps. The Hackensack river watershed inflow for this day was comparable to the inflow of the Passaic River, or two orders of magnitude higher than its historic median, making the CDOM contribution of the Bergen County plant comparatively insignificant (also see Figure 13). The contribution of the fifth end member, the Port Richmond WPCP outfall (not shown), is predicted by the model to be much less important due to an apparent 1:100 dilution factor in the vicinity of the outfall hypothesized to be due to the strong exchange of Raritan Bay, Newark Bay, and Upper Harbor waters happening through the Kills. Also visible are the mixing zone of the Hackensack and Passaic rivers (a line beginning at their confluence at Kearny Point and running along Newark Bay) and the mixing zone of the Hudson and Raritan rivers, running from Sandy Hook, NJ to Great Kills Harbor at Staten Island, NY, nicely delineating the boundaries of Raritan Bay and the Lower New York Harbor.

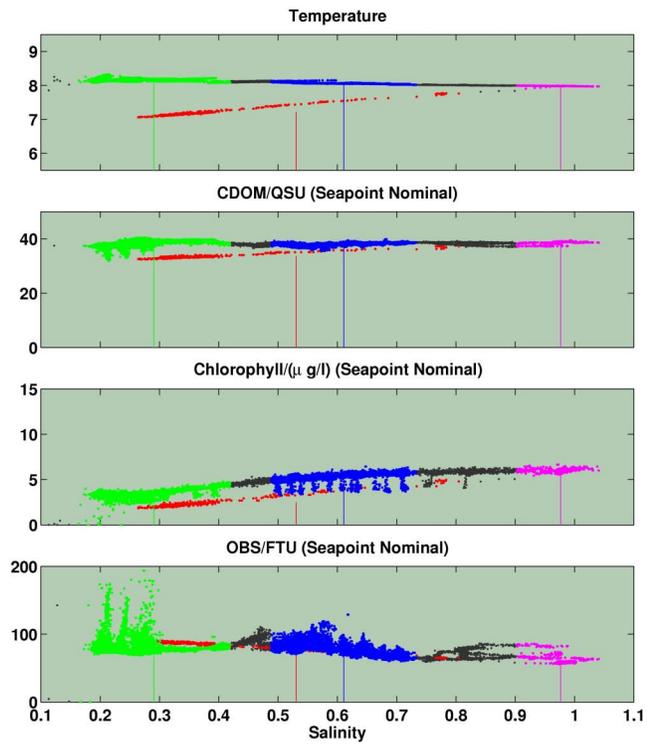
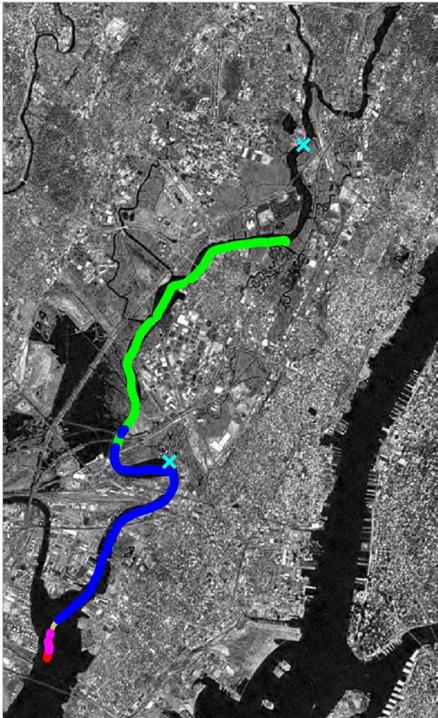
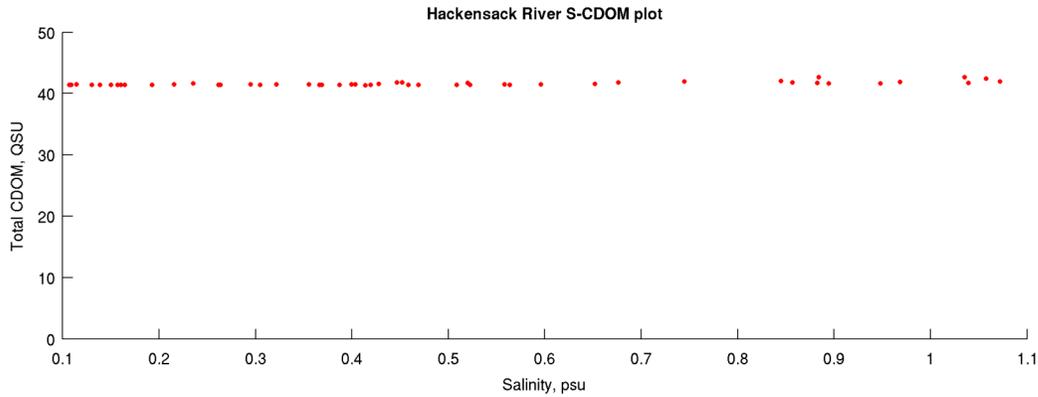


Figure 13. NYHOPS HIGHRES validation for April 17, 2007 major flooding event. Top panel shows high resolution NYHOPS CDOM model results predicted for the time observations (lower panels) were taken, between 16 and 18 hrs ET. Both model and data show that the Hackensack, influenced by historic inflows, was a freshwater river all along its span at the time that CDOM concentrations were measured. Both model and data show CDOM concentrations throughout the river close or equal 40 QSU, with an almost imperceptible slight increase at the Newark Bay outlet. Although due to tidal time logistics the observations stopped south of the Bergen County plant outfall, the CDOM load from the plant was diluted by the historic freshwater drainage inflows and cannot be discerned in the model.

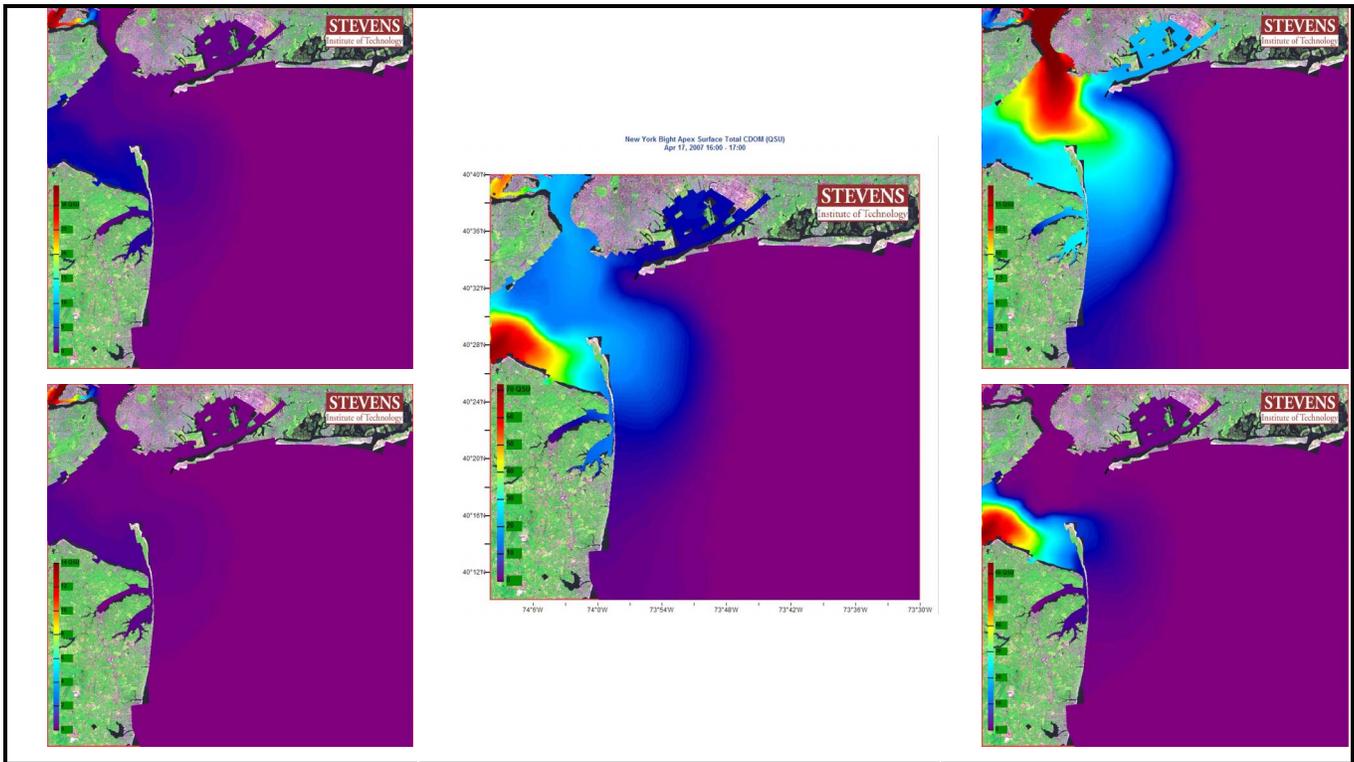


Figure 14. Screen captures of high resolution NYHOPS-predicted CDOM for April 17, 2007 16:30 ET, same time frame as in Figures 12 and 13. This date was one of major flooding all along northern New Jersey due to very intense and long-lasting rainfall. The various end members (clockwise from top left, Passaic River, Hudson River, Raritan River, and Hackensack River including the Bergen County water treatment plant), combine their strengths to create the central image which depicts the predicted CDOM concentration in the surface waters of the New York Bight Apex. Note the different scales in the end member color maps. Due to record-breaking river flows, considerable CDOM concentrations were predicted by the NYHOPS model to exit New York Harbor proper and influence the New York Bight region, hugging the northern New Jersey Atlantic shoreline carried by southbound alongshore transport.