Scientific Visualization and Data Modeling of Scattered Sediment Contaminant Data in New York/New Jersey Estuaries

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ABSTRACT

Sediments in many parts of the New York and New Jersey estuary system are contaminated with toxic organic and inorganic compounds by different sources. Because of the potential environmental consequencesΓdetailed information on the spatial distribution of sediment contaminants is essential in order to carry out routine shipping channel dredging in an environmentally responsible wayΓand to remediate hot spots cost-effectively and safely. Scientific visualization and scatter data modeling techniques have been successfully applied in analyzing the sparse sampling data of sediment contaminants in New York and New Jersey estuariesΓthe underlying spatial characteristics of which are otherwise difficult to comprehend. Continuous realizations of contaminant concentrations in the region were obtained by using a spectral domain-decomposition scattered data model and IBM Data Explorer which is a software package for scientific data visualization.
Keywords: scattered data modelingΓspectral domain decomposition method.

1. INTRODUCTION

Parts of the New York and New Jersey estuary system contain some of the most polluted sediments in the waterways of the United States [4–9]. Because of the potential environmental consequencesΓgreat care must be exercised in regard to any actions involving excavation of these contaminated sedimentsΓsuch as periodical dredging of the shipping channels to keep them open for navigationΓor dredging related to contaminant remediation. Figure 1 shows the outline of the estuaries in the region of concern.

Figure 1. Outline of New York and New Jersey estuaries.

Historical sediment core sampling locations in this region are scattered (e.g.Γthose in Jamaica Bay shown in Figure 2). It is very difficult to obtain a general view of the contaminant distribution

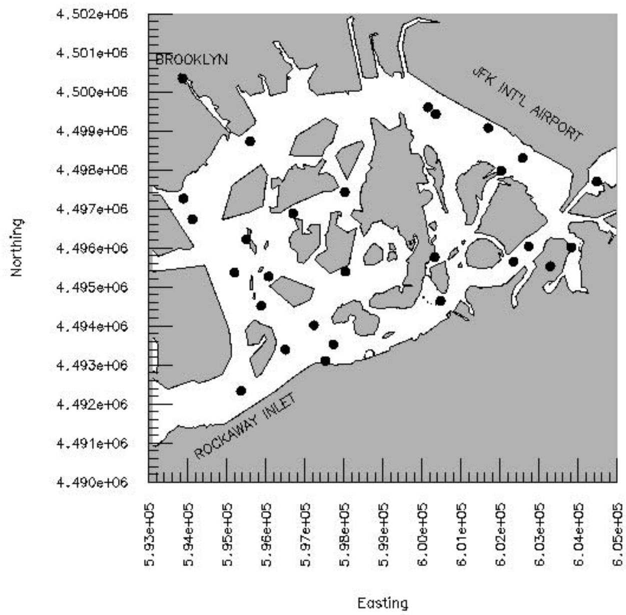

Figure 2. Sediment core sampling locations in Jamaica BayΓNY.

by just looking at the data itselfΓno matter if it is in tables or in scatter plots. Scientific data visualization and modeling are essential in order to provide the management and the engineers with detailed information on the distributions of the contaminated sediments so that dredging can be carried out safely and cost-efficiently.

2. SCATTERED DATA MODELING

The most simple and straightforward way of displaying scattered data is to list them in a tableΓor place them on a scatter plot. The drawback of this kind of straightforward discrete presentations is that they fail to convey important information about the spatial characteristics represented by the data. Data modeling is necessary in order to produce quality presentations which impart this information. Figure 3 illustrates the function of a data model.

Among the traditional data modeling methodsΓthe inverse distanced weighted approximation is a relatively simple and computationally inexpensive approach to interpolate scattered data. The major drawback which significantly affects the quality of the output of an data interpolator rooted in this method is that it ignores any local shape properties implied by the data [8].

Historical sediment core sampling data in the New York and New Jersey estuaries are poorly conditioned for data modeling. The sampling locations are sparse and irregularly distributed. MoreoverΓin narrow estuaries (e.g.ΓPassaic RiverΓNJ)Γthe aspect ratio between the scale of sampling interval in the cross-channel direction and that in the along-channel direction is huge. These conditions are likely to result in a failure of a commercially available data interpolator.

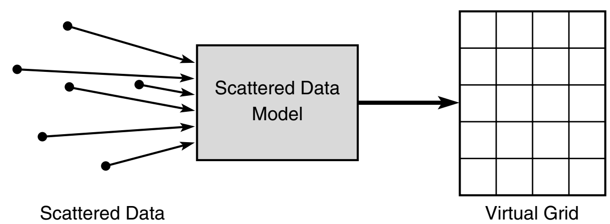

Figure 3. Mapping scattered data onto a virtual grid through a data model.

The scattered data modeling technique used in the present work is based on a spectral domain decomposition numerical method. In recent yearsΓthe spectral domain decomposition method has been successfully applied in high-resolution geophysical fluid dynamics models [3Γ5Γ6Γ7]. The superior computational properties of this methodΓsuch as geometrical flexibilityΓhigh convergence rateΓand suitability for parallel computingΓmake it a good choice for data modeling as well. The principles of this method can be described as follows:

Let the geometrical domain of interest Ω be decomposed into K subdomainsΓΩ^eΓe=1Γ2Γ...ΓK; $\bigcup_{e=1}^{K} \Omega^e = \Omega$. Each subdomainΓ$\Omega_e$Γcontains a number of data points. The local approximation of the distribution functionΓu^eΓin subdomain Ω_e can be written as

$$u^e(\mathbf{x}) = \sum \mathrm{u}_\mathrm{n}^\mathrm{e} \psi_\mathrm{n}^\mathrm{e}[\xi(\mathbf{x})]$$

where ψ_n^e (n=0Γ1Γ2Γ..) are piecewise Chebyshev polynomials [1]Γξ is the spatial variable in the phase domain.

The global approximation of the distribution function is then taken the following form

$$u(\mathbf{x}) = \bigcup_{\mathrm{e}=1}^{\mathrm{K}} \mathrm{u}_{\mathrm{h}}^{\mathrm{e}}[\xi(\mathbf{x})]$$

In order to ensure continuityΓproper boundary conditions have to be assigned at the interfaces of the subdomains. Depending on the degree of smoothness requiredΓ C^0 (continuous at the 0^{th} order) and/or C^1 (continuous at the 1^{st} order) interface continuity conditions have to be imposed:

$$u_\alpha(\mathbf{\Gamma}) = \mathrm{u}_\beta(\mathbf{\Gamma})$$
$$u'_\alpha(\mathbf{\Gamma}) = \mathrm{u}'_\beta(\mathbf{\Gamma})$$

where Γ is the interface between subdomains Ω_α and Ω_β.

To further smooth the output of the spectral multi-domain interpolantΓa low-pass filter is applied to remove noises which result from the irregularities of the data. Computational details regarding the spectral domain-decomposition data modeling methodology are described in [7].

3. VISUALIZATION RESULTS

After the spectral domain-decomposition data model poured the scattered sediment core sampling data onto a virtual gridΓthe rest of data visualization task was carried out by using the IBM Data Explorer (DX) visual programming tool [2]. Images with detailed information on the spatial distribution of sediment contaminants in the estuaries of concern were thus created.

Figure 4 is the result of using three dimensional continuous realization technique to show dioxin "hot spots" in Passaic RiverΓNJ. In this visualization exampleΓthe three dimensional image can be freely rotated to any desired angle on the fly to allow examination of the scope of the infected region with the predefined contamination level (hot spot). This visualization technique can provide necessary aid to the formation of a well informed plan for remediation and/or dredging of the contaminated sediments. Figure 5 is a three dimensional contour plot of the concentration of PCB in Passaic River. The horizontal coordinates in these figures are New Jersey State Plane coordinatesΓand the vertical coordinate is in feet. Because the discrepancy between the scale of the horizontal dimension of the Passaic River and that of the vertical dimensionΓthe visual object (the Passaic River) in Figure 5 was stretched in the vertical direction to 700 times its real length in order to show the contaminant distribution pattern in the vertical direction. Figure 5 shows that there are large areas in the Passaic River where the sediment PCB concentration level can be as high as 10 ug/kg or moreΓwhich far exceeds EPA's standard. By applying the "slicing" functionality of the DX programming toolΓwe can easily view contaminant distribution along any transections of the study region. Figure 6 reveals the structure of a dioxin hot spot in a transection taken in the cross-river direction (Passaic River). It indicates that the highest dioxin discharge rate at this particular location occurred during a time period in the pastΓsince the core of the hot spot is a couple of feet below the sediment surface. Remediation steps must be taken to protect the environment should any dredging actions take place (which are necessary in order to keep the navigation channel open).

Sediment contaminant concentration images were also made for Jamaica BayΓNewark BayΓand New York Harbor (Figures 7Γ8Γ9). Our visualization results show that despite the fact that the pollution situation has improved somewhat in recent yearsΓthe sediment contaminant levels in many parts of the New York and New Jersey estuaries are still very high. We find that color images of continuous realization work better in revealing hot spots in narrow estuaries than discrete contour lines (Figures 7 and 10).

4. CONCLUSIONS AND FUTURE WORK

Scientific visualization and data modeling are useful tools in analyzing the scattered data of sediment contaminants in New York and New Jersey estuariesΓthe underlying spatial characteristics of which are otherwise difficult to comprehend. The images of the sediment contaminant distribution in three spatial dimensions allow us to obtain detailed information about the scope and distribution pattern of a particular pollutant.

The density of data locations as well as the manner in which the data locations distribute can

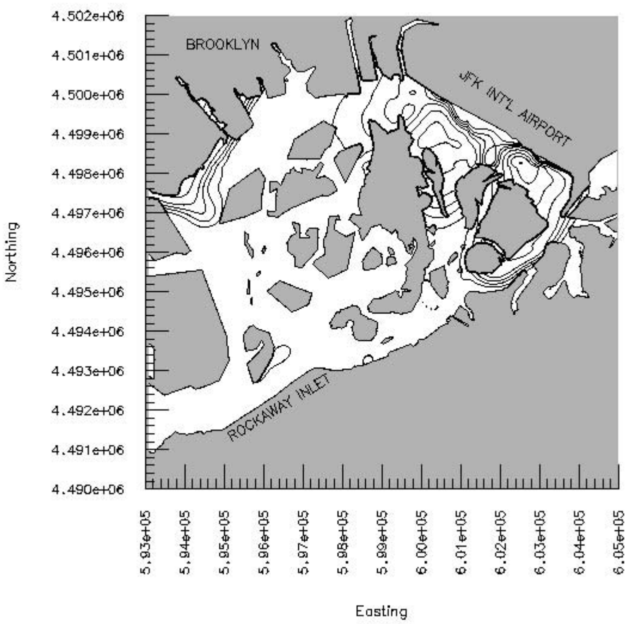

Figure 10. Contour map of Total DDT surficial sediment concentration in Jamaica BayΓNY.

significantly affect the quality of the data model output andΓ thereforeΓ that of the visualization products. In order to improve the accuracy of the data model output for the sediment contaminant distributions in the New York/New Jersey Harbor systemΓwe need to increase the overall sediment core sampling density in the entire regionΓwhich currently is very sparse.

We are planning to develop a 4D (time+space) simulation and visualization model for the sediment transport process. This modelΓ together with the scattered data modelΓcan serve as powerful tools to systematically monitor the environmental conditions of our waterwaysΓas well as to predict future changes of such conditions.

5. ACKNOWLEDGEMENT

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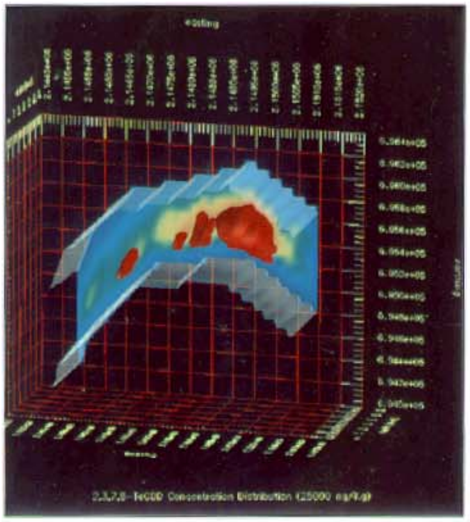

Figure 4. 2, 3, 7, 8-TeCdd Concentration Distribution (25000 ng/Kg)

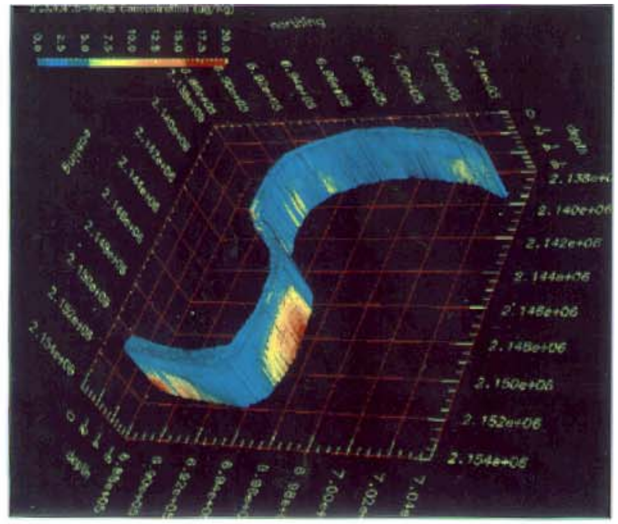

Figure 5. PCB Sediment Concentration in Passaic River, NJ

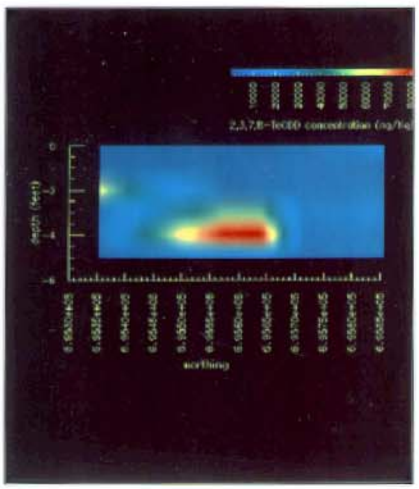

Figure 6. 2, 3, 7, 8-TeDD Concentration transaction at easting 2147000

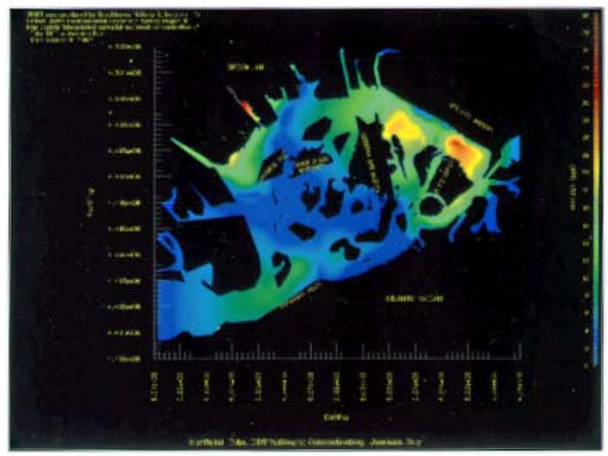

Figure 7. Surficial Total DDT Sediment Concentration-Jamaica Bay

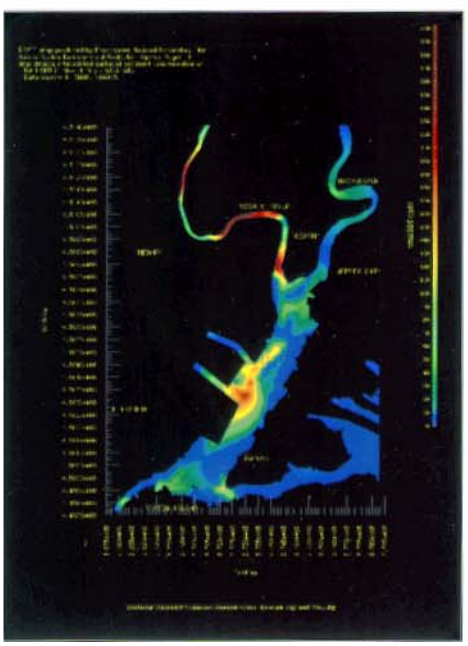

Figure 8. Surficial Total DDT Sediment Concentration-Newark Bay and Vicinity

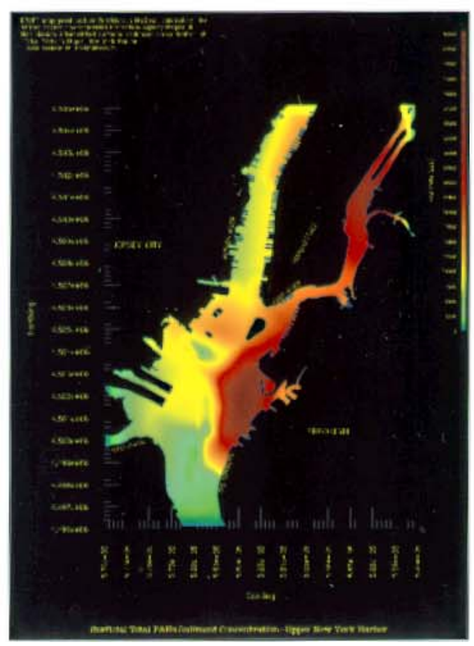

Figure 9. Surficial Total PAHS Sediment Concentration-Upper New York Harbor