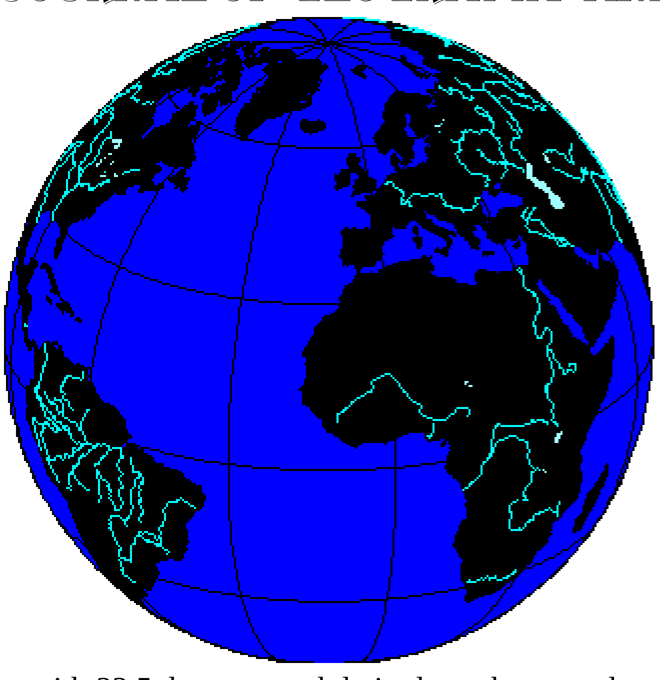
SOLSTICE:

AN ELECTRONIC JOURNAL OF GEOGRAPHY AND MATHEMATICS



Earth: with 23.5 degrees north latitude as the central parallel.

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The purpose of Solstice is to promote interaction between geography and mathematics. Articles in which elements of one discipline are used to shed light on the other are particularly sought. Also welcome are original contributions that are purely geographical or purely mathematical. These may be prefaced (by editor or author) with commentary suggesting directions that might lead toward the desired interactions. Individuals wishing to submit articles or other material should contact an editor, or send e-mail directly to sarhaus@umich.edu.

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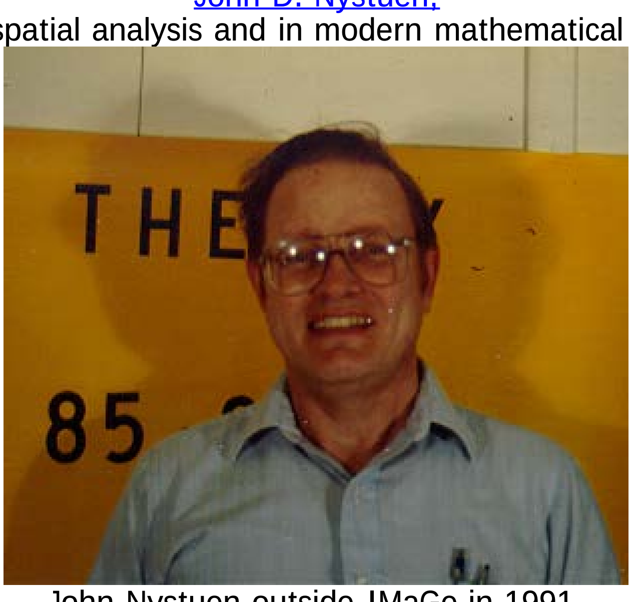
DEDICATION

It is with the greatest of pleasure that this issue of Solstice is dedicated,
on the occasion of his retirement from The University of Michigan,
to the career of
John D. Nystuen,
pioneer in spatial analysis and in modern mathematical geography.



John Nystuen outside IMaGe in 1991.

Metropolitan Mining: Institutional and Scale Effects on the Salt Mines of Detroit

John D. Nystuen
The University of Michigan
Revised June 1999; based on earlier work as noted at the end.

Abstract

Mining, as with most industrial activities, is constrained by logistics, which involves technological matters of transportation, material conversion and energy costs. Convention and law also influence the activity. These are institutional matters involving mineral rights and access to resources. Both logistical and institutional configurations exist in a space/time context and in metropolitan areas, where geographic space is a complex mosaic of private and public property, the limits to an industrial activity are nicely illustrated in the example of the salt mines of Detroit.

Introduction

Metropolitan mining refers to industries that extract minerals or other materials from locations within highly urbanized regions. The example of a metropolitan mine in Detroit reveals some interesting interplay between technological and institutional constraints. Industrial activities operate in a space/time envelope partially confined by logistics, the physical task of moving people, things and energy through space and time. Physical movements depend on the speed and cost of transportation and communication--technological matters employed to overcome the cost of space. Social/economic behavior is also constrained by conventions; bound by abstract, imaginary barriers that establish entitlement and prescribe behavior--institutional matters that have temporal components associated with expectation and risk. Social behavior often has geographical manifestations. We know how to behave on account of where we are: on sacred ground, on private property, or in a public forum. Private property, although a very abstract and multi-dimensional concept, often includes strong geographical connotation. In this paper we make reference to one kind of private property, mineral rights used to gain access to the salt deposits under Detroit.

Every geographical process whether social or physical also has an intrinsic or operational scale associating relative size of the elements contained in the process. Two components are involved: (a) the diameter of the system which may be defined as the longest extent or distance between interacting parts and (b) the unit size or smallest extent of an elementary element. An elementary element is a part which is treated as a single unit in the system and which cannot be subdivided. This requires some elaboration. Everything and every action take some minimum time and space. We allocate time and space among activities according to their needs. We jostle about and shoulder one another aside to arrange our affairs spatially and temporally---that is geographically. If by chance or otherwise some elements cannot maintain their minimum unit size, they cease to exist, in Hägerstrand's words; everything has a minimum extent and duration, a kind of kernel or minimum unit of existence (Hagerstrand, 1970). This is true of abstract, institutional content of our environment as well as in the logistical matters we face. The interplay between space and time and scale are nicely illustrated in the Detroit Salt Mines of the International Salt Company.

The Geography of Salt Mining

The Detroit salt mine was started 1906 and finally closed operations in 1985 after millions of tons of salt had been removed. The work created extensive man-made caverns under the city that remain today. The Detroit mine has a rather complex shape that is intriguing to geographers and that calls for some explanation (Figure 1).

In mining the first issue is the matter of the location of the natural resource. As it happens salt deposits underlay much of the Michigan Basin and extend all across the Midwest into New York State. Anywhere in this region "straight down" carries one back in time. Nearly one quarter of a mile under Detroit we are brought back 390 million years into the Paleozoic Era to a Silurian Sea in which deep salt deposits were made in a series of layers now covered with shale, limestone and sandstone overburden. The Detroit salt mine worked a 30 foot thick seam of rock salt at 1135' below the surface, one of several layers of salt (Figure 2). The top 90 to 100 feet from the surface is unconsolidated glacial drift full of water under high pressure and permeated with hydrogen sulfide. This proved to be a difficult mix of material through which to drive a mineshaft.

The mineshaft was started in 1906 eleven years after the salt was discovered under the city. The mineshaft proved very difficult to dig and eight men lost their lives in the effort. By 1914 after bankruptcy and acquisition by a rival salt company the mine began production and shortly reached a production of about 10,000 tons per year. A second larger shaft 16 feet in diameter was sunk in 1922. Despite this width the largest opening is only 6 foot by 6-foot square as room for ventilation, the salt skips (the containers to lift the salt), power lines, elevators for men and equipment must all fit in the shafts. Both shafts were used. Large diesel trucks, front loaders, drilling rigs, conveyor machines, milling machine and machine shops to maintain them are all underground brought down the narrow shafts in pieces and even cut into pieces by acetylene torch and reassembled underground.

At a regional scale the location of the mine may be taken as market oriented. Because the resource is spatially ubiquitous, that is, available anywhere in the Midwest, proximity to the highest market potential dictates choice of location, hence the metropolitan location. There are only four rock salt mines in the northeast quarter of the country. Each is in a metropolitan area with an upstate New York site as an exception. The cost of sinking the shafts appears too great for widespread use. For some decades there has been an alternative to open shaft mines. Brine wells are more common. In such installations the salt is removed by pumping hot water into the salt bed and withdrawing brine. Large Midwestern industrial users such as chemical companies can sink their own brine wells and are no longer customers for the rock salt mines. The overwhelming proportion of the rock salt is used to clear road of ice during winter months. That market is seasonal and varies with the severity of the winters. As it is always more efficient for an industrial operation, including mining, to have steady production, the older, closed parts of the salt mine are used for storage of processed salt. Storage is a time transfer process. The mine is very dry which means that the stored salt does not deteriorate over time.

The salt sells for about $18 to $20 per ton f.o.b. the mine. (f.o.b. means free on board--the customer pays for hauling it away). The mining company sells either f.o.b. or delivers and adjusts the price accordingly. They lease or contract for trucks from hauling companies when they offer to deliver. Transportation costs vary by size of truck, 25 cents per ton-mile for trucks with 10 to 15 ton capacity down to a minimum of 12 cents per ton-mile for truck/trailer rigs with 55 to 60 tons capacity. Great Lake carriers are much less, perhaps 3 cents per ton-mile. At these prices it doesn't take much distance to double the price of the salt: 167 miles by truck, 667 miles by water (Figure 3). The diagram gives some sense of when customer, principally municipalities, county and state road maintenance departments, will forego salt and turn to sand and plows to some other alternative to clearing streets in snow emergencies.

In 1960, the International Salt Company opened a new rock salt mine in Cleveland. It is located exactly on the shore of Lake Erie. This location has both logistical and institutional advantages. They are able to ship salt in bulk by lake carrier at much reduced costs per ton-mile than overland shipments. Cleveland is able to ship salt past Detroit to lake ports in the upper Great Lakes at costs lower than it could be delivered from the Detroit mine. The Detroit mine has shipped by water in the past and is not much more than one-half mile from the turning basin of the River Rouge where they have loading facilities. This half-mile gap must, however, be bridged by trucking and loading costs that exceed the cost of the sixty-eight nautical mile shipment from Cleveland. The Cleveland mine also, by mining out under Lake Erie, leases mineral rights from a single owner, the State of Ohio. This permits a more efficient mine layout. In 1987 the Detroit mine ceased to operate, put out of business in part by its awkward shape. The Detroit Metropolitan area now gets its salt from Cleveland and Windsor, Ontario, where in the later location the mine is of optimal shape and extends out under the Detroit River on the Canadian side. In Canada, mineral rights laws were more favorable to the salt companies.

Site Conditions. Pure salt crystals make a very hard rock and hard rock mining techniques must be employed in the mine. The active mine face is undercut ten feet, (the undercut is called a kerf), powder holes drilled and the rock salt blasted free. Very large trucks, primary crushers, conveyor belts and milling machines all underground, are used to create the finished rock salt graded by several sizes. Up to twenty-five percent of annual production can be stored in the empty rooms of the mine (200,000 to 250,000 tons) as annual productions of up to one million tons are mined in normal years. The active face of the mine is 23 to 25 feet high and 50 to 60 feet wide. Eight hundred to nine hundred tons of salt are freed in each shot. Salt weighs about one ton per cubic yard in place. The seam being worked yields about 40,000 tons per acre of recoverable salt. These dimensions are important when we turn to considering technological and institutional scale effects in the mining operation. Long rooms, fifty feet wide and twenty-five feet high are formed by the mining operations. Huge salt pillars sixty by eighty feet on a side are left in place to hold up the roof. The salt is strong enough that no shoring is necessary. No cave-in has ever occurred. This type of hard rock mine is called "pillar and room" (Figure 4). Sixty-two percent of the salt is recovered using this method. The mine has been operating since 1914. Something like 1700 acres have been excavated. Figure 1 shows a plane view of the mine as it exists today. These boundaries are not exact because the mine managers were reluctant to release a map of the mine to me for reasons that will become obvious as I continue this story. Notice the irregular shape of the mine and that it extends essentially only westward from the mineshaft. This does not make sense technologically. Logistics are a big part of the mining costs and logistically the best shape would be compact, nearly circular with the mineshaft at the center. Two transport technologies are employed underground, trucks costing at best perhaps 20 cents per ton-mile and conveyor belt at perhaps eight cents per ton-mile. The spatial problem is to minimize the sum of these two costs from the active mine face to the shaft. The radius of a circle of 1700 acres is 0.92 miles. The active mine face is currently over four miles away: 434% farther than the ideal. If half the distance were by truck and the rest by conveyor belt this distance would cost 35.3 cents per ton more than the ideal. For 800,000 tons per year that is an additional $280,000. So why does the mine have this shape? The answer is institutional and relates back to that concept of the kernel of existence.

This permits a more efficient mine layout. In 1985 the Detroit mine ceased to operate, put out of business by its bad shape. The Detroit Metropolitan area now gets its salt from Cleveland and Windsor, Ontario, where in the later location the mine is of optimal shape and extends out under the Detroit River on the Canadian side. In Canada, mineral rights laws were more favorable for the salt companies.

Mineral Rights and Transaction costs. In Michigan every landowner having free title to his or her land owns the mineral rights for all minerals beneath it. The salt company will offer around $2000 per acre for mineral right or about $0.05 per ton. This is highly variable depending upon the size and strategic position of the property under

consideration. Under some circumstances the company might be willing to buy the land outright only in order to obtain the mineral rights. In other circumstances mineral rights would be worth very little. The size and location of the property is the key to its value. This can be understood through analysis of institutional factors. There is a minimum transaction cost associated with each mineral rights transaction. First negotiations must be made, and upon agreement, the transfer or leasing of mineral rights must be assigned in each property deed and recorded at the county court house records office. If two lawyers are involved, one for each side, there exists a minimum institutional friction for each transaction that in a rock bottom estimate would total more than one thousand dollars at ninety to a hundred dollars per hour per lawyer for a day or day and a half of work. It could be much more. If the legal fees were $1200, this translates into all the value of the mineral rights for a lot just under a two-thirds of an acre in size. Most city lots in high-density residential blocks are 1/8 to 1/6 of an acre in size. The mineral rights for a lot 1/6-acre in size are worth perhaps $333. Would you like to sell your mineral rights to the salt company? Never mind that your lawyer would probably get most of this payment.

There is another problem. Time as well as space is involved. For security in continuity of operations the company is interested in procuring mineral rights ten years or more in advance of actual use. That means that they are not willing to pay more than the present worth for the mineral rights they will use in ten years. For a lot that has about $400 worth of mineral rights--a lot 91 feet on the side or just under 1/5 acre, the present worth at 5.5% interest rate is $234 -- perhaps under two hours of a lawyers time. Under these conditions, the salt company preferred to take options on the mineral rights and promise to pay royalties whenever they actually mined under your property. Under this arrangement they were willing to offer to pay $2000 per acre in ten years or so, and to make cash payments as the salt is mined. The seller needed to evaluate this option based on the present worth of that future payment using the same interest formula. For both parties the transaction costs (i.e., the lawyers' fees) had to be paid up front. There were also some accounting expenses associated with this procedure and again it did not pay to deal with small landowners--the mining company was not interested in anything under an acre, in fact, deals involving several acres at a time are clearly preferable. Therefore residential land use marks the limit to the mining activities. This is abundantly clear from looking at the map. The shape of the mine is understandable when considering institutional constraints in addition to technological ones. Although the mine management did not discuss the matter with me, some simple calculations are sufficient to give a sense of the minimum property size a metropolitan mining company would be willing to consider for acquiring property rights. The present value of $2000 for each acre of mineral rights to be used in ten years is $1171 at 5.5% interest. If legal and closing costs were to be kept at, say 5% of total mineral rights costs, then supposing an efficient law firm could handle the matter in one day, $800 worth of legal fees in current money would require a $16,000 transaction to be attractive to the mine operators, ($800 = .05P, P= $16000). The figure $16,000 divided by $1170.86 (present value per acre) yields 13.7 acres at 5.5% interest and 22.8 acres at 11% interest. The salt company would not be interested in any place under twelve or so acres with more normal interest rates and nothing under twenty-two acres given high interest rates characteristic of the 1980's unless some special strategic location existed that might affect mine operations. Both a unit space and a time duration, twelve acres and ten years, can be seen to affect the overall dimensions and actual shape of the mine.

There are more subtleties. Space and time combine to create velocity. The velocity at which things happen affects geographic patterns as well. Twenty acres are mined in a typical year amounting to 800,000 tons of salt. The tonnage must move from the active face of the mine to the shaft. Some time ago the company negotiated a purchase of mineral rights from a group of small lot owners in which all had to agree to the sale of their mineral rights or no deal was to be made. The plan was to cut off about 3000 feet of underground travel route to reduce underground transportation costs. Diesel trucks with 22 ton load capacities are used underground along with conveyor belts. I estimate the diesels may cost 20 cents/ton-mile (I did not have exact figures from the salt company). A saving of 3000/5280 of a mile at 20 cents/ton-mile would be 11.4 cents per ton. A similar saving if the conveyor system were extended through the bypass would be 4.5 cents per ton. At 800,000 tons per year the savings in truck operating costs would be $91 thousand per year. An amount of $36 thousand would be saved if the conveyor system were shortened by this much. The bypass opened up approximately one-quarter square mile (160 acres), which if mined at about 20 acres per year would mean eight years of operation. What is the present worth of a stream of income (savings) of $91 thousand per year for eight years? The interest formula for an annuity or stream of savings for this period yields a present value of $576,000.

The bypass involved extending mining operations down a residential street where property owners on both sides owned the mineral rights to the center of the street. A corridor 200 feet wide and 1900 feet long was sought. The by-pass corridor is shown in Figure 1 located on the north side of the central part of the mine. It makes the shape of the mine more complex topologically by creating a hole in the shape. The corridor contains 8.17 acres. Using the truck technology, the by-pass was worth $70 thousand per acre in savings. The strategic location was thus worth thirty-five times the usual mineral rights payments. To realize this fact one must account for the effects of space and time simultaneously, that is, by considering the velocity of activities. Gross sales at twenty dollars a ton and 800,000 tons per year amount to sixteen million dollars. Savings of $91,000 by better spatial arrangement within the mine amounts to one half percent of the gross per year. I have no idea what profit margins for a mine of this sort amount to, but I suspect five percent of gross might be generous. Perhaps the corridor was worth ten percent of profits per year. It pays to pay attention to geography. The prospects for the mine are good insofar as acquisition of property rights are concerned. The mine abuts parcels that exceed ten acres in size at several points on its perimeters. These in turn open up to territory several times the area that has been mined up to the present. The access was greatly improved once they acquired mineral rights under a railroad right-of-way and more recently under the Interstate Highway in the City of Allen Park. These linear forms create many links to large parcels under various industrial properties in these communities. I conclude that the mining company had opportunities for acquiring mineral rights sufficient to carry them well into the next century. The outside dimension and shape of the mine can thus be seen to be a function of an elementary element that would be no smaller than ten acres and which, in turn, depended upon institutional factors interacting with logistical considerations. Certain strategic locations might be exceptions.

Metropolitan salt mining may seem to be a rather special topic but I detect a generalization here that sheds light on how spatial and temporal parameters can be used in understanding other urban patterns. I have thought it odd that high-density town house developments have sprung up at the edge of metropolitan regions and unfortunate also because of the increase in travel effort this pattern creates. I suspect that changes in construction costs and in the working of the financial market have increased the size of minimum viable developments to the extent that suitable large properties can only be found on the edge of the metropolitan areas. The urban region is a mosaic, made up of discrete elements and not a continuous surface as is implied in certain urban models. When a system is made up of discrete units the minimum viable unit space for an activity affects the larger dimensions of the activity and should enter into calculations used to explain the general patterns.

In spatial terms alone the key variable is density of the activity measured in dollars per unit area. In temporal terms the key variable is the annual return on initial investments and transaction costs measured as an intensity or dollar amount per unit of time. In simultaneous space and time the measure is dollars per unit area per unit time. Where/when there is a moving front as in the case of metropolitan mining or subdivision expansion, the key variable is a velocity or rate of advance. In discrete space/time, one must take into account an appropriate estimate of the minimum extent and duration of all elementary elements (kernels) in the system and their interactions.

References:

Rodolfo J. Aguilar (1973) Systems Analysis and Design in Engineering, Architecture, Construction and Planning, Englewood Cliff, N. Jersey: Prentice Hall, Inc.

Hagerstrand, Torsten (1970) "What about people in Regional Science?" Papers, Regional Science Association, v. 24, pages 7-21.

International Salt Company (1971) Salt City Beneath Detroit (brochure).

I extend thanks to Mr. Jim McDonald, the Manager of these mines, for the information he shared with me about their operations.

"Metropolitan Mining: Institutional and Scale Constraints on the Salt
Mines of Detroit", paper presented to the Northeast Regional Science
Conference, Hunter College, New York City, May 7, 1983.

A version of the paper was also presented by the author as part of a
lecture entitled: "Place, Location, Time and Timing: Form and Texture in Space/Time" given as the Reginald G. Golledge Invited Lecture, Department of Geography, University of California, Santa Barbara, April 8, 1999.

ANIMAPS III: COLOR STRAWS, COLOR VOXELS, AND COLOR RAMPS

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BACKGROUND

Background is important not only in color visualization but also in fostering a deep understanding of a variety of abstract concepts. One place to begin any background study of color is with the four-color problem (now, "theorem;" Appel and Haken, 1976). For centuries, mathematicians have concerned themselves with how many colors are necessary and sufficient to color complicated maps of many regions. (Two regions are said to be adjacent, and therefore require different colors, if and only if they share a common edge; a common vertex, alone, is not enough to force a new color.) The answer depends on the topological structure of the surface onto which the map is projected. When the map is on the surface of a torus (doughnut) seven colors are always enough. Surprisingly, perhaps, the result was known on the torus well in advance of the result for the plane (then again, the plane is unbounded and the torus is not). The same number of colors that work for the plane will also work for the sphere (viewing the plane as the sphere with one point removed). However, it was not until the last half of the twentieth century, aided by the capability of contemporary computing equipment to examine large numbers of cases, that the age-old "four color problem" became the "four color theorem." Appel and Haken (1976) showed that four colors are always enough to color any map in the plane (hence the University of Illinois postage meter stamp of "four colors suffice" announcing this giant result).

The world of creating paper maps and publishing them has traditionally been one that is black and white: color processing is expensive and often has been prohibitive. Nonetheless, cartographers, photographers, and others have developed a number of strategies for considering color, independent of how many colors suffice to color a map in the plane. Indeed, Arthur Robinson noted (Robinson, 1960, p. 228),

> "Color is without a doubt the most complex single medium with which the cartographer works. The complications arise from a number of circumstances, the major one being that even yet we do not know precisely what color is. � The complexity is due to the fact that, so far as the *use* of color is concerned, it exists only in the eye of the observer."

Like the mathematician, the cartographer, too, has significant unsolved problems associated with the concept of color.

Thus, color choice and use is typically tailored to "standard" reactions, by a typical observer, to color. The effect of color on an observer is often captured using the following terms as primitive terms: hue, saturation, and luminosity.

- Hue is the term used to describe basic color. Blue, red, and green are all hues. White light passing through a prism is broken up into the spectrum of the rainbow composed of a variety of hues. The basic hues evident in this process are often referred to as spectral hues and these can be used to generate a progression of interstitial hues to fill in between the evident hues.
- Saturation is a measure of the amount of hue in a color; it is also referred to as intensity. Thus brilliant colors are more intense than are light pastels.
- Luminosity is a measure of relative lightness or darkness of a color. Color can be matched against a gray scale to make this measurement. One would expect, for example, that most shades of yellow are lighter than most shades of red.

In the more contemporary environment of the desktop computer, users of various software packages in common use are exposed to the hue-saturation-luminosity set of primitive terms on a regular basis. In addition, they see the RGB (Red-Green-Blue) description also using three primitive terms and the printer's (photocopier's) environment of separations into layers based on CMYK (Cyan-Magenta-Yellow-Black). A color wheel (Figure 1) can help the user to design strategies for color change: to decrease magenta, for example, subtract magenta, or add cyan and yellow (opposite from magenta).

COLOR STRAWS AND COLOR VOXELS

One obvious way to look at color, given two sets of primitives each with three elements, is as an ordered triple in Euclidean three-space. Indeed, that is how color maps are set up in contemporary software such as Netscape, Microsoft Office, and so forth. Hue is measured across a horizontal x-axis (Figure 2) and saturation is measured along a vertical y-axis (Figure 3). The result is a square or rectangle with vertical strips of color corresponding in order to the pattern on the color wheel. A third axis of luminosity (a gray scale) is often seen as a strip to the right of this square (Figure 4). It serves to match the selected color against light/dark values.

Figure 2. Animated color map: shows change in resulting hue as one moves across the x-axis.
Figure 3. Animated color map: shows change in resulting saturation as one moves along the y-axis.
Figure 4. Animated color map: shows change in resulting luminosity as one moves along the z-axis.

These animated color maps fix two dimensions and allow a third one to vary. That variation shows up in the small rectangle to the lower left of the color map and also in "straw" to the right of the plane region. In all three cases, hue is the variable mapped on the horizontal axis, saturation is the variable mapped on the vertical axis, and luminosity is the variable mapped in the straw to the right. Thus, in Figure 2, luminosity is fixed at 120 as indicated by the small arrow to the right of the straw. Saturation is fixed at 180 along the left side of the rectangle. Only hue is allowed to vary, as shown in the progression of the crosshair movement. The small rectangle to the lower left of the color map changes in color to show the hue of the current position of the crosshair. Thus, to see a hue-straw, one would need to take all 256 colors available in the flashing rectangle and stack them up in order of progression. Similarly, one can allow saturation to vary and keep hue and luminosity fixed (Figure 3). When luminosity is once again fixed at 120, and hue at 180, a structurally identical situation occurs (to that above). To see a saturation-straw, one would need to take all 256 colors available in the flashing rectangle and stack them up in order of progression. The final case, in Figure 4, keeps hue and saturation fixed and allows luminosity to vary. Thus, one imagines a point in the base hue/luminosity plane fixed at (180, 120) and variable height shown in the luminosity straw reflecting changes in the single color-point as one alters luminosity. In this latter case, the obvious straw that appears is in fact the actual luminosity straw sought. In two cases, there is no evident straw of color and in the third there is; visualization is not impossible but it is made difficult.

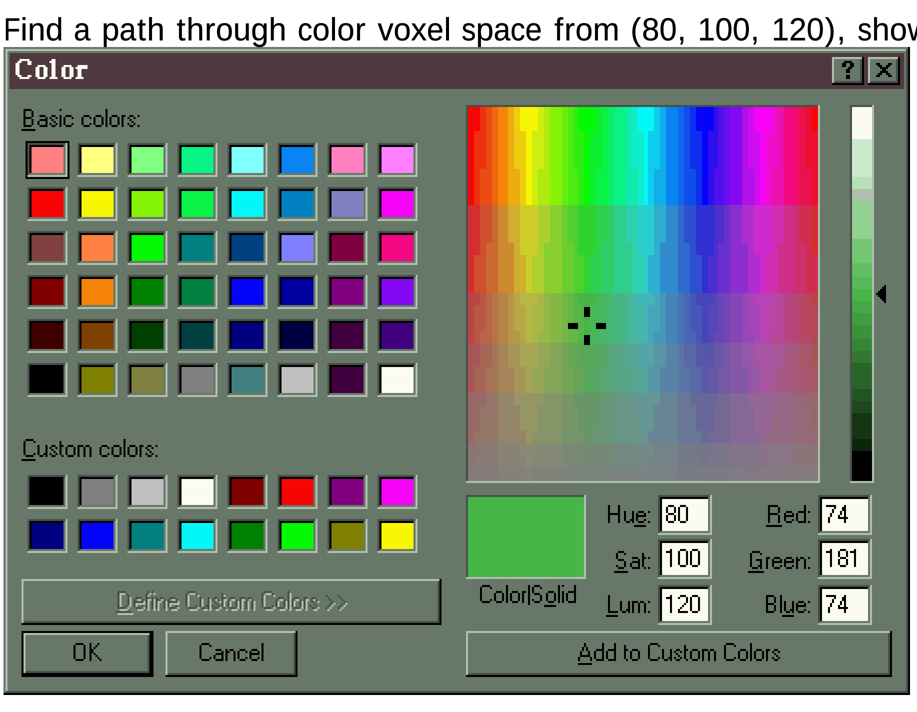
An alternate way to visualize all of this is to think of a cube (in 3-space) of 256 units on a side. Label the x-axis as hue, the y-axis as saturation, and the z-axis as luminosity. Then, draw a plane parallel to the base plane (bottom of the cube) at height 120. Fix lines at 180 within that plane: one with hue=180 and one with saturation=180. These two lines trace the paths of the crosshairs, respectively, in Figures 2 and 3. What the cube approach also shows clearly is that there are really a set of voxels (volume pixels) making up the cube: there are 256 straws available for each of the three variables. Since 256=2^8, there are therefore 2^8 * 2^8 * 2^8 = 2^24 = 16,777,216 voxels within the color cube (note the reliance on discrete mathematics and discrete structuring of a normally continuous object).

The notion of looking only at voxel subsets within a single plane parallel to a face of the cube is limiting within this large, but finite, set of possibilities. In choosing sequences of color there may well be reason to follow a diagonal, to tip a plane, or to find various other ways of selecting subsets of color, as a smoothed color ramp, from this vast array. It is to these possibilities that we now turn.

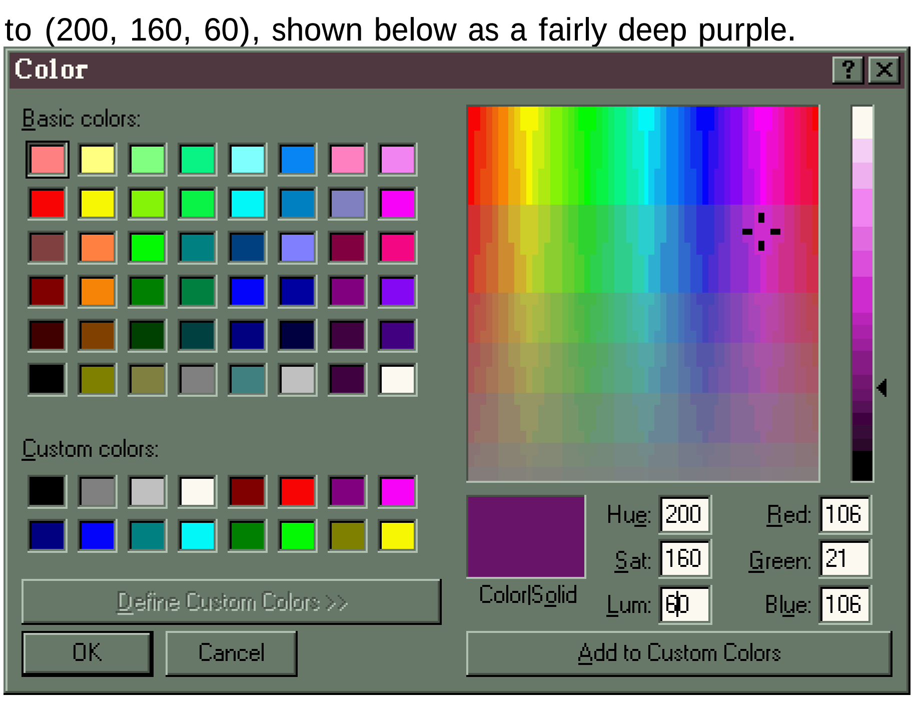
COLOR RAMPS: ALTERNATE METRICS

The problem of finding color ramps linking one color to another can be captured simply as follows. To find a ramp joining two colors, A and B, first represent each of A and B as an ordered triple in color voxel space. Then, the problem becomes one of find a path from A to B. Because one is limited to integer-only arithmetic, divisibility of distances often will not be precise; thus, one is thrown from the continuous realm of the Euclidean metric into considering the non-Euclidean realm of the Manhattan metric (of square pixel/cubic voxel space). Algorithms for finding shortest paths between two arbitrary points using integer-only arithmetic will therefore apply to colors mapped in color space as well as to physical locations mapped on city grids. To see how these ideas might play out with colors, we consider an example that will lead to an animated color ramp.

Find a path through color voxel space from (80, 100, 120), shown below as a medium green



to (200, 160, 60), shown below as a fairly deep purple.



One set of points through which to pass, spaced evenly (not always possible), is given in the table below. The left-hand column shows values of hue, the middle column values of saturation, and the right-hand column values of luminosity.

80	100	120
90	105	115
100	110	110
110	115	105
120	120	100
130	125	95
140	130	90
150	135	85
180	140	80
170	145	75
180	150	70
190	155	65
200	160	60

Figure 5 shows an animation using the path outlined in the table above. The crosshairs show the movement along the path while the flashing color in the rectangle below the color map shows the associated color ramp. Clearly, the choice of path is not unique: geodesics are not unique in Manhattan space. From this analysis, we see that the following theorem will hold.

Theorem.
The determination of color ramps joining two colors is abstractly equivalent to finding paths in Manhattan space between two arbitrary points (where geodesics are not unique).

One might wonder what would happen when other color characterization schemes are considered. We suspect that a similar analysis will follow. For, in a related, but not identical, manner the RGB scheme may also be represented as describing color using 3-space. In that scheme, the gray scale comes out as a 45 degree diagonal. Computer scientists offer a color code containing six alpha-numeric characters, appearing in pairs of hexadecimal code that also serve as a 3-space. Generally, though, the various schemes offer only visual slices through this three-dimensional color space along axes or in other "expected" ways. Different vantage points offer different perspectives, however. Pantone color formula guide books offer one physical set of straws by which to probe 3D color space. The theorem above offers a comprehensive mathematical set.

REFERENCES

Appel, K., and Haken, W. A proof of the 4-color theorem. *Discrete Mathematics*, 16, 1976, no. 2 (and related references).

Arthur H. Robinson, *Elements of Cartography*, 2nd Edition, 1960. New York: Wiley.

RELATED LITERATURE

Sandra L. Arlinghaus, William C. Arlinghaus, John D. Nystuen. The Hedetniemi Matrix Sum: An Algorithm for Shortest Path and Shortest Distance, *Geographical Analysis*, Vol. 22, #4, Oct. 1990, pp. 351-360.

Sandra L. Arlinghaus, William C. Arlinghaus, John D. Nystuen. The Hedetniemi Matrix Sum: A Real-world Application, *Solstice*, Vol. I, No. 2, 1990. http://www.imagenet.org

Sandra L. Arlinghaus, William C. Arlinghaus, John D. Nystuen. Discrete Mathematics and Counting Derangements in Blind Wine Tastings, *Solstice*, Vol. VI, #1, 1993. http://www.imagenet.org

Sandra L. Arlinghaus, William C. Arlinghaus, Frank Harary, John D. Nystuen. Los Angeles 1994--A Spatial Scientific Study, Solstice, Vol. V, #1, 1994. http://www.imagenet.org

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BOOK REVIEW

André I. Khuri, Thomas Mathew, and Bimal K. Sinha, *Statistical Tests for Mixed Linear Models*, John Wiley & Sons, 1998, 352 pp., $69.95 (cloth).

The decomposition of variance components is an essential part of data analysis for researchers employing mixed models�i.e., those containing both fixed and random effects. In recent years, analysts have made significant breakthroughs regarding statistical tests for such models. *Statistical Tests for Mixed Linear Models*, written by André Khuri and his co-authors, presents a comprehensive, mathematical overview of these methods and extends past work to include hypothesis testing.

Traditional, analysis of variance (ANOVA) models are well developed for fixed effects models, which are those in which the researcher has complete control over assignment of factors and factor levels. For models with random effects (as often exists in observational studies, where for example, subject educational level varies but is not under the control of the researcher), too, ANOVA models have long existed. Models with both types of effects, however, present some special challenges, and *Statistical Tests for Mixed Linear Models* lays out appropriate solutions.

Covering both balanced (those with equal numbers of observations in all subclasses) and unbalanced models (those with at least one subclass with a different number of observations compared to the others), *Statistical Tests for Mixed Linear Models* presents derivations of both exact and optimal tests for variance component models, as well as guidance on using such tests for hypothesis testing. While little attention is paid to conducting such tests with commonly available statistical software (e.g., SPSS™ or SAS™)�in many instances such software cannot directly perform the tests described�the authors usually provide sufficient information to allow users (especially advanced users) to complete the tests on their own, generally aided by specific output given in standard ANOVA tables. In several places, conceptual algorithms are given to allow the reader to conduct tests not offered in standard software.

Designed primarily as a course textbook, *Statistical Tests for Mixed Linear Models* includes student exercises at the end of each chapter, an appendix that gives the solutions to selected problems, and an ample bibliography. Beyond formal use in the classroom, the book also may serve as a reference guide for researchers beyond their student years who wish to know more about exact or optimal tests for mixed linear models. Interested readers, however, should be aware that this is not an introductory text on experimental design or ANOVA. To make best use of *Statistical Tests for Mixed Linear Models*, readers should be well versed in both. For a good overview of experimental research design, see, for example, Montgomery (1991). A classic work on ANOVA is Scheffe (1959), and many more fine texts have come since.

For those interested specifically in the optimal tests presented in *Statistical Tests for Mixed Linear Models*, the authors recommend previous familiarity with the concept of optimal tests and the methods for deriving such tests (such as Lehmann, 1986). Readers would do well to heed this advice; indeed, Khuri and his co-authors would have greatly aided their readers had they included an introduction to optimal tests in *Statistical Tests for Mixed Linear Models*.

Viewed as either a textbook or a reference guide, *Statistical Tests for Mixed Linear Models* suffers from one major drawback for researchers who primarily use statistics (as opposed to statisticians who advance statistical methods)�too few applications of developed procedures to real data. No doubt, the almost purely mathematical exposition is not a drawback for statisticians or mathematicians, but it can be frustrating for those who want to learn how best to apply advanced methods to actual data. Working the sample problems may alleviate some of this concern.

Those already comfortable with mixed models will find much of use in *Statistical Tests for Mixed Linear Models*. The tests described therein will enable researchers to make stronger and more certain inferences from their data. Finally, teachers of advanced courses in experimental data analysis will have collected in one place many of the most recent advances in the field.

REFERENCES

Lehmann, E.L. 1986. *Testing Statistical Hypotheses*, Second Edition. New York: Wiley.

Montgomery, D.C. 1991. *Design and Analysis of Experiments*. New York: Wiley.

Scheffe, H. 1959. *The Analysis of Variance*. New York: Wiley.

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University of Michigan

BOOK REVIEW

Castells, Manuel (1996). *The Rise of the Network Society (The Information Age: Economy, Society and Culture, Volume 1)*. Malden, MA: Blackwell Publishers, Inc. (556 pages, bibliography 51 pages, index 23 pages).

Manuel Castells has helped to alter the direction of social research with such works as *The Urban Question* (1977) and *The City and the Grassroots* (1983). In his latest book, *The Rise of the Network Society* (part one of a three-part series), Castells attempts both to synthesize decades of intellectual thought (his own and others) and to generate a conceptul structure to embody the myriad societal changes occurring worldwide. The book provides a thought-provoking description of the collective human experience during the current Information Age. While the book attempts to cover many aspects of the economy, society, and culture, the most novel aspects of the book, which Castells refers to as "the architecture and geometry" of the network society, should be of particular interest to geographers and mathematicians, alike.

Castells begins the book with a description of how the Information Technology (IT) Revolution is distinct from the Industrial Revolution. The distinguishing characteristic of the new IT paradigm that particularly affects social and economic transformations is its "networking logic". As opposed to the linear or serial set of relationships during the Industrial Revolution, epitomized by Fordist mass production, new information technologies are facilitating more complex interactions that are organized by networks. Clearly, network structures are not new, but Castells argues that new information technologies, such as the Internet, allow such structural types to pervade social and economic processes.

Castells describes how the fundamental aspects of networks allow for changes that are leading to a variety of transformations, such as decentralization within firms, telecommuting of workers, interactions in the virtual community and economic globalization. Networks can expand without limits by simply integrating new nodes that share the same means of communication with other nodes. Networks are much more flexible and malleable, because there is no overarching organizational or institutional shape.

Building upon his previous research in political economy and urban sociology, Castells views the current transformations in urban form around the world as the manifestation of the interconnections and linkages between cities. The "space of flows," which pertains to flows of capital, flows of information, flows of technology, etc., intertwines the fates of nodes in the network, but does not predetermine them. Winners and losers in the global urban network are difficult to predict and are continuously emerging from the space of flows. Perhaps an example of Castells�s view is the economic uncertainty that ensued after the East Asian crisis in 1997. The path of the pandemic affected the Pacific Basin, but did not travel to the US (yet), as widely feared.

Potential future research in planning based on Castells� framework should center upon the policy implications of the new IT paradigm. When are local planning initiatives held hostage by the global forces in the space of flows? Are different networks destined to remain infinitely apart due to incompatible means of communication? Are there policy remedies for the segmentation of society based on those who are networked and those who are not? Geographers and mathematicians will recognize the applicability of a graph theoretic approach to decipher complex networks, which may be appropriate for a planning context. Such methods can, for example, identify critical linkages that would cripple a section of the network if severed.

Castells interjects several heady topics throughout the book such as the logic of capital accumulation, the relationship between society and postmodern architecture, and the social arrhythmia of the natural lifecycle. The book is written like a very long essay, since Castells does not provide rival explanations for many of the issues included in the book. There are also some unclear aspects of his framework. For example, why do some networks have nodes that dominate flows, as in the urban network, whereas others do not, as in the Internet? Although Castells specifically states that "this is not a book about books", the amount of detail compiled from a wide variety of sources tends to detract from the originality of his thoughts. For the reader who already knows about the rise of Silicon Valley and the Latin American debt crisis, Castells� synopses are redundant. For the reader new to topics related to the high-technology economy and globalization, however, this book provides a comprehensive survey of the literature.

The Rise of the Network Society is a book to read neither quickly nor only once. If time is a limiting concern, however, the final three chapters, which include a provocative discussion about space and time in the network society, incorporate the crux of Castells�s vision of society at the turn of the 21st century.

Reviewed by

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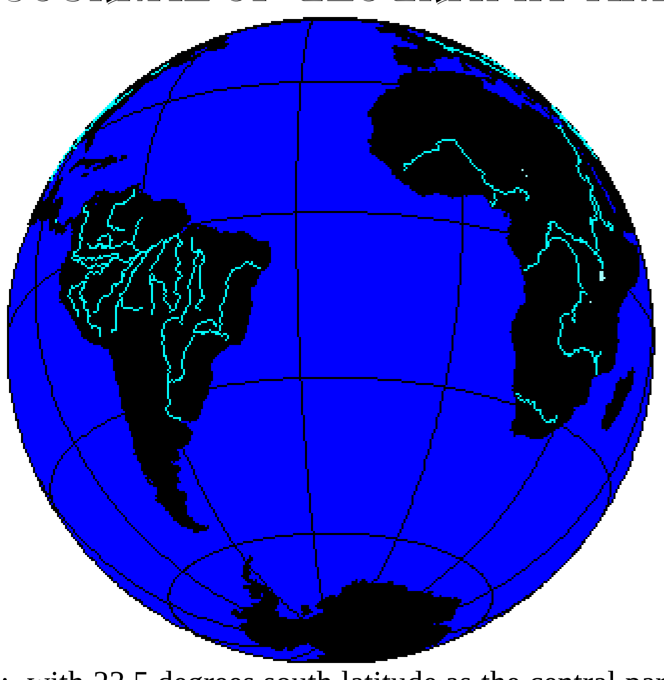
SOLSTICE:

AN ELECTRONIC JOURNAL OF GEOGRAPHY AND MATHEMATICS



Earth: with 23.5 degrees south latitude as the central parallel.

VOLUME X

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DECEMBER, 1999

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EMail from Readers.

This past month IMaGe has received four notes of the same content, all having to do with the astronomical winter solstice of 1999. We reprint the material, forwarded by:

Robert F. Austin
John D. Nystuen
James R. O'Neil
Sandra S. Westrin

in the table below.

"This year will be the first full moon to occur on the winter solstice [in 133 years], Dec. 22, commonly called the first day of winter. Since a full moon on the winter solstice occurs in conjunction with a lunar perigee (point in the moon's orbit that is closest to Earth) the moon will appear about 14% larger than it does at apogee (the point in its elliptical orbit that is farthest from the Earth). Since the Earth is also several million miles closer to the sun at this time of the year than in the summer, sunlight striking the moon is about 7% stronger, making it brighter. Also, this will be the closest perigee of the moon of the year since the moon's orbit is constantly deforming. If the weather is clear and there is snow cover where you live, it is believed that even car headlights will be superfluous. On December 21st, 1866 the Lakota Sioux took advantage of this combination of occurrences and staged a devastating retaliatory ambush on soldiers in the Wyoming Territory. In laymen's terms all this means it will be a super bright full moon, much more than the usual AND it hasn't happened this way for 133 years! Our ancestors 133 years ago saw this. It will be 100 years or so years from now until our descendants will see this again."

FESTSCHRIFT CD

for John D. Nystuen Career Commemorative Symposium, held in Ann Arbor, September 24, 1999, at the Pendleton Room of the Michigan Union has been produced. People who attended the symposium will be receiving a CD in the mail. Other interested parties, should feel free to contact John Nystuen concerning it (nystuen@umich.edu) with a copy of the e-mail note to IMaGe (sarhaus@umich.edu).

Listening to Raindrops

Jeffrey A. Nystuen

Senior Oceanographer

University of Washington

presented at

The John D. Nystuen Symposium

The University of Michigan

Ann Arbor, Michigan

24 September 1999

Abstract: The sound of rain underwater is loud and distinctive. It can be used as a signal to detect and measure oceanic rainfall. These measurements are needed to support climatological studies of the distribution and intensity of global rainfall patterns. Individual raindrops produce sound underwater by their impacts onto the ocean surface and, more importantly, by sound radiation from any bubbles trapped underwater during their splashes. Because different raindrop sizes produce distinctive sounds, the underwater sound can be inverted to quantitatively measure drop size distribution in the rain. Acoustical Rain Gauges (ARGs) are being deployed on oceanic moorings to make long-term measurements of rainfall using this acoustical technique.

1. Why listen to raindrops?

Rain is one of the most important components of climate. Knowledge of its distribution and intensity is important not only to farmers and flood control planners, but also to meteorologists, oceanographers and climatologists. This is because the formation of a raindrop in the air is accompanied by latent heat release. This heat release is one of the primary sources of energy driving atmospheric circulation. Thus, understanding the global patterns of distribution and intensity of rainfall is needed to improve weather and climate forecasting. Furthermore layers of relatively fresh water due to rain at the ocean surface are now thought to significantly affect oceanic circulation[1], another component of global climate. Unfortunately, rainfall is also very difficult to measure, especially over the ocean where few people live and where rain gauges commonly used on land don't work. But we all know that rain falling onto a tin roof makes a lot of noise, and so does rain falling onto water. In fact, rain falling onto water is one of the loudest sources of underwater sound. So maybe we can measure oceanic rain by listening to it from below the ocean surface.

2. How do raindrops make sound underwater?

There are actually two components to the sound generated by a raindrop splash. These are the splat (impact) of the drop onto the water surface and then the subsequent formation of a bubble underwater during the splash. The relative importance of these two components of sound depends on the raindrop size. Surprisingly, for most raindrops, it is the bubble that is, by far, the loudest sound source. Bubbles are one of the most important components of underwater sound[2]. They have two stages during their lifetimes: screaming infant bubbles and quiet adult bubbles. As a bubble is created, in general it is not in equilibrium with its environment. It radiates sound (screams) to reach equilibrium. The frequency of the sound is well defined[3]:

$$f_r = \frac{1}{2\pi a}\sqrt{\frac{3\gamma P_0}{\rho_0}}$$

and depends on bubble radius, a, local pressure, P_0, local water density, ρ_0, and a geophysical constant, $\gamma = 1.4$. The important observation is that the size of the bubble is inversely proportional to its resonance (ringing) frequency. Larger bubbles ring at lower frequencies. The sound radiated is often loud and narrowly tuned in frequency (a pure tone). But quickly, after just tens of milliseconds, a bubble in water becomes a quiet adult bubble and changes roles. It absorbs sound, and is especially efficient absorbing sound at its resonance frequency.

Naturally occurring raindrops range in size from about 300 microns diameter (a drizzle droplet) to over 5 mm diameter (often at the beginning of a heavy downpour). As the drop size changes, the shape of the splash changes and so does the subsequent sound production. Laboratory and field studies[4,5] have been used to identify five acoustic raindrop sizes (Table 1). For tiny drops (diameter < 0.8 mm), the splash is gentle, and no sound is detected. On the other hand, small raindrops (0.8 - 1.2 mm diameter) are remarkably loud. The impact component of their splash is still very quiet, but the geometry of the splash is such that a bubble is generated by every splash in a very predictable manner[6]. These bubbles are relatively uniform in size, and therefore frequency, and are very loud underwater. Small raindrops are present in almost all types of rainfall, including light drizzle, and are therefore responsible for the remarkably loud and unique underwater "sound of drizzle" heard between 13-25 kHz, the resonance frequency for these bubbles.

TABLE 1. Acoustic raindrop sizes. The raindrop sizes are identified by different physical mechanisms associated with the drop splashes (4, 5).

Drop size	Diameter	Sound source	Frequency range	Splash character
tiny	<0.8 mm	silent		gentle
small	0.8-1.2 mm	loud bubble	13-25 kHz	gentle, with bubble every splash
medium	1.2-2.0 mm	weak impact	1-30 kHz	gentle, no bubbles
large	2.0-3.5 mm	impact loud bubbles	1-35 kHz 2-35 kHz	turbulent irregular bubble entrainment
very large	>3.5 mm	loud impact loud bubbles	1-50 kHz 1-50 kHz	turbulent irregular bubble entrainment penetrating jet

Interestingly, the splash of the next larger raindrop size, medium (1.2-2.0 mm diameter), does not trap bubbles underwater, and consequently medium raindrops are relatively quiet, much quieter than the small raindrops. The only acoustic signal from these drops is a weak impact sound spread over a wide frequency band. For large (2.0-3.5 mm diameter) and very large (> 3.5 mm) raindrops, the splash becomes energetic enough that a wide range of bubble sizes are trapped underwater during the splash, producing a loud sound that includes relatively low frequencies (1 - 10 kHz) from the larger bubbles. For very large raindrops, the splat of the impact is also very loud with the sound spread over a wide frequency range (1-50 kHz). Thus, each drop size produces sound underwater with unique spectral features that can be used to acoustically identify the present of that drop size within the rain.

An example of the underwater sound field generated by a heavy thunderstorm recorded in Miami, FL is shown in Figure 1. The variations in the sound field are associated with changes in the drop size distribution (Fig. 2). During the heavy convective downpour, with rainfall rates reaching 150 mm/hr, very large raindrops are present and the sound field is loud across the entire spectrum (1-50 kHz). At the end of the convective downpour, a long drizzle begins. This phase of the storm has few large drops. The sound generated by small drops dominates the sound field producing the distinctive 13-25 kHz peak in the sound field associated with drizzle. At the end of the event, a few large drops are again present and once again the sound field becomes elevated below 10 kHz. Because the sound signatures for each drop size are unique, it is possible to invert the underwater sound field to acoustically estimate the drop size distribution within the rain[5] (Fig. 2). Once an acoustic drop size distribution is obtained, a variety of interesting features associated with the rain can be calculated, for example, rainfall rate or median drop size.

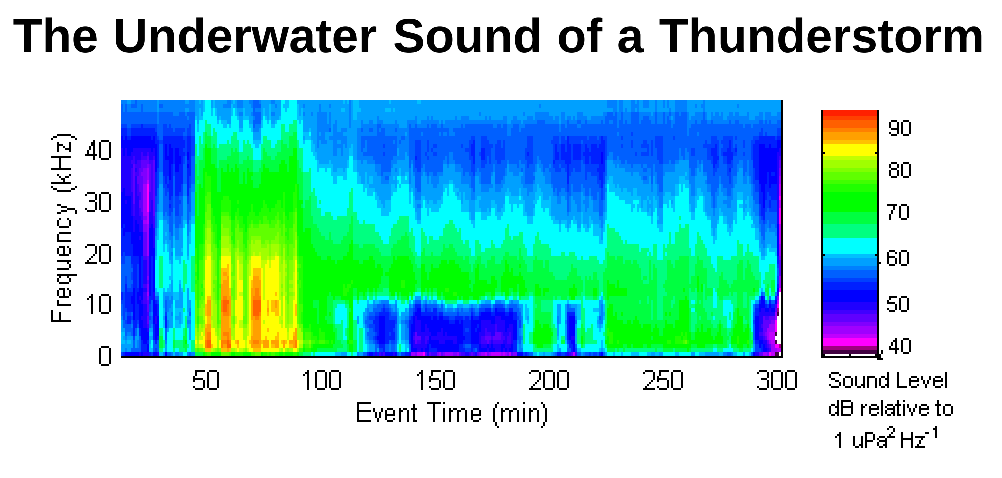

Figure 1. The underwater sound field during a thunderstorm. The changes in the sound are closely associatied with changes in the drop size distribution of the rain.

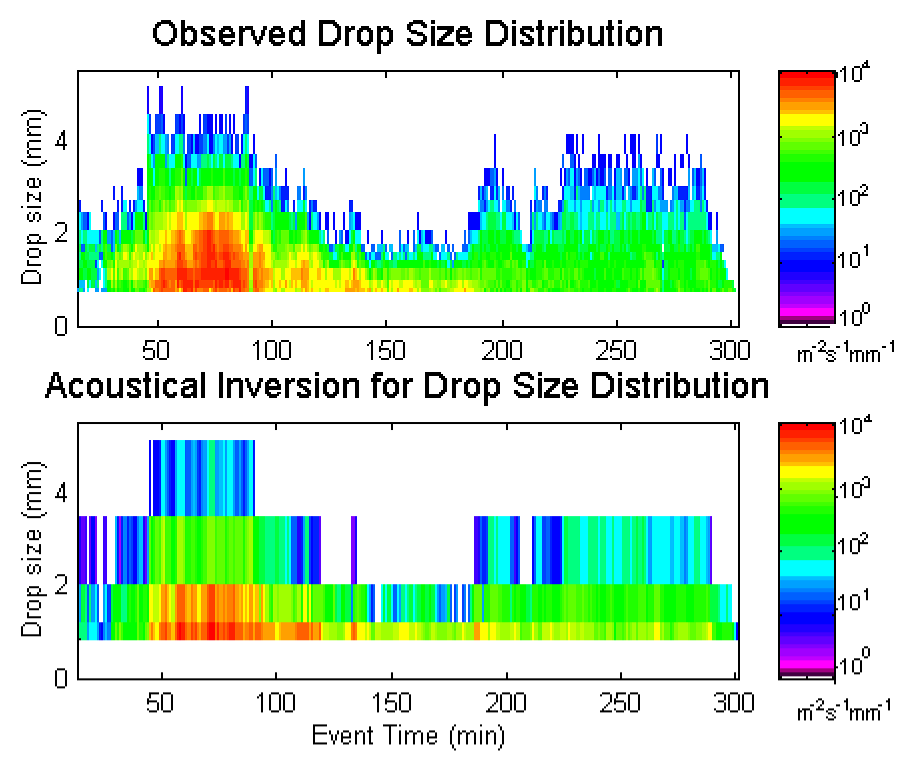

Figure 2. The observed drop size distribution in the thunderstorm and the acoustical inversion based on the unique sound signatures for each drop size. Very large raindrops are present during the heavy downpour. During the following drizzle, only small and medium raindrops are present and the sound of drizzle is heard between 13-25 kHz. Still later, a few large raindrops are present and the sound levels below 10 kHz become higher once again.

3. Listening to the Ocean: Acoustic Rain Gauges

In order to measure rain at sea, Acoustic Rain Gauges (ARGs) have been designed and built at the Applied Physics Laboratory, University of Washington. The ARG consists of a hydrophone (underwater microphone), some electronic circuitry, a low-power sampling computer and a battery package designed to operate the ARG without servicing for up to a year. The ARG is attached to a mooring line, and can be placed at any depth, although practically the depth is limited by the crushing strength of the instrument case. Every few minutes the ARG "wakes up", evaluates and records the underwater sound field. Currently, the ARG design is autonomous from the surface float, and the recovery of data awaits recovery of the mooring. In the future, real-time transmission of the data will be needed to provide useful data for weather forecasting.

Figure 3. Dr. Jeffrey A. Nystuen holding an Acoustic Rain Gauge (ARG). This instrument is designed to be clamped onto an oceanic mooring and will record the underwater sound for one year.

4. Detection and Measurement of Rain at Sea

When listening for rain in the ocean, the first step is to identify the sound as rain. There are lots of other sounds underwater, including the sounds of waves breaking, man-made sounds and biological sounds. Biological and man-made sounds are sometimes very loud and, if they contain frequency components which overlap the rain-generated sound, then they can prevent acoustical measurement of rain. These noises are usually intermittent or geographically localized. Some locations where persistent "noise" is present includes harbors (shipping and industrial activity) and snapping shrimp colonies. Snapping shrimp are from a family of shrimp species which make very loud "snaps" and that inhabit shallow tropical waters. Fortunately, the frequency content of most sounds is unique to their sources, and can be used to identify the sources, including rain, drizzle and whitecaps. Some examples of oceanic sound spectra are shown in Fig. 4.

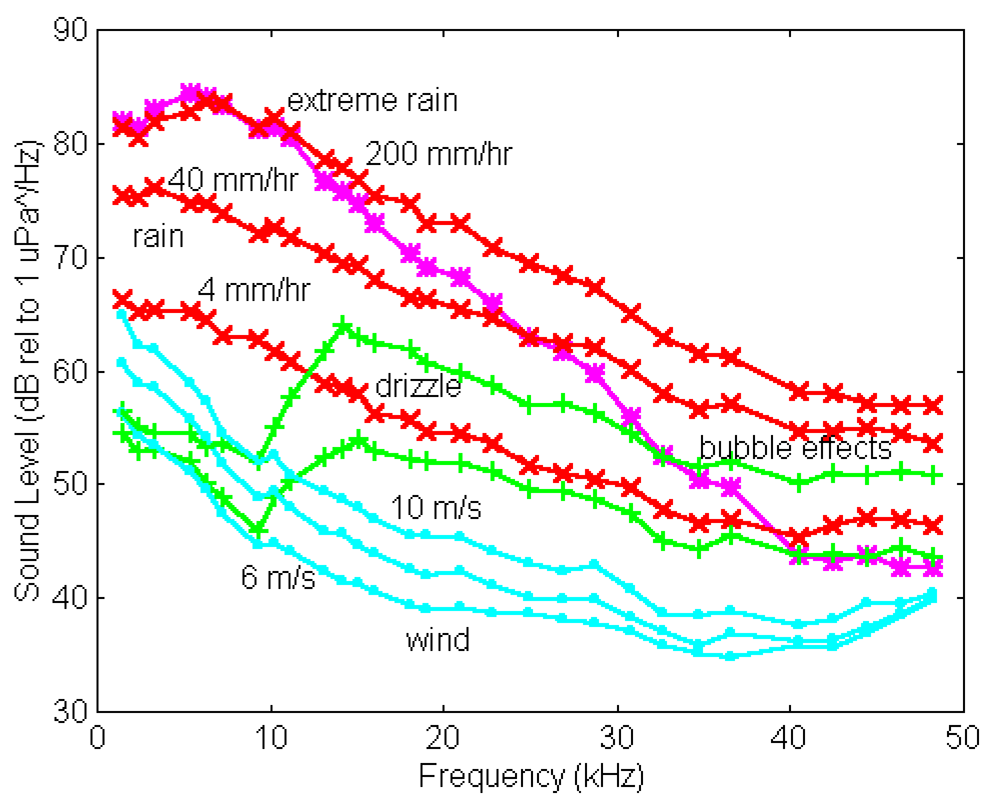

Figure 4. Examples of underwater sound spectra recorded from an oceanic mooring in the South China Sea. The sound spectra from wind-only conditions (cyan) show an uniform shape and a sound level which is proportional to wind speed. The sound of drizzle (green) shows the characteristic peak associated with the sound generation mechanism of the small raindrops. The sound of heavy rain (red) is louder and includes lower frequencies. The sound of extreme rain includes sound generated by very large raindrops and is very loud. It also shows the effect of "quiet adult bubbles". Two spectra from extreme rain (200 mm/hr) are shown. The first (red) shows extremely high sound levels at all frequencies. The second (magenta) shows relatively lower sound levels above 10 kHz. This spectrum was recorded five minutes after the first, and yet the rainfall rate was still the same. A layer of bubbles had been injected into the sea surface. New "rain sound" has to pass through the bubble layer to reach the ARG sensor, and is partially absorbed by the bubbles. Since smaller bubbles (higher resonance frequency) are less buoyant than larger bubbles, they stay in the water longer and thus, this bubble effect is most noticable at higher frequencies.

Most of the time, it is not raining and no man-made or biological noises are present. When this is true, the sound is from the whitecaps generated by wind and can be used to quantitatively measure wind speed[7] as the number of whitecaps is proportional to wind speed. The shape of the sound spectrum generated by breaking waves is controlled by the distribution of bubble sizes generated by the breaking wave[8]. An interesting feature of the wind-generated signal is an apparent limit to the loudness of the sound at higher frequencies. This is due to quiet adult bubbles absorbing the higher frequency sound levels[9]. Because of their smaller size, bubbles which absorb high frequency sound stay in the water longer and can form effective layers of sound absorbing bubbles.

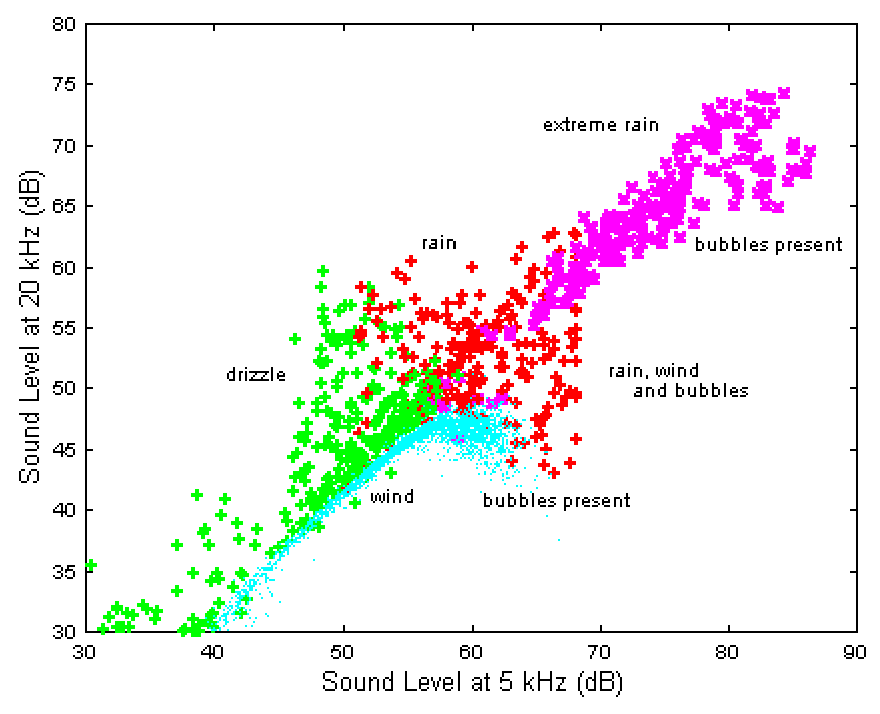

Figure 5. Acoustic weather classification uses features of the underwater sound spectrum to identify the sound source: wind (cyan), drizzle (green), rain (red), extreme rain (magenta) and to detect ambient bubbles.

Using Figure 4, the differences between wind-only and rain-generated spectra often appear to be subtle. However, by presenting the data in a different manner (Fig. 5), acoustic identification of different weather conditions becomes apparent. The sound of rain and drizzle contains relatively more high frequency sound than the sound from wind-only conditions. Furthermore, it is much louder. Even drizzle, under low wind speed conditions, has sound levels which can be orders of magnitude louder than wind-only conditions. The characteristic sound of drizzle, the 13-25 kHz peak, is sensitive to wind and has not been detected when the local wind speed is over 8-10 m/s. On the other hand, the sound from heavy rain is very robust and can be detected even in very high wind speed conditions (over 20 m/s)[10]. Extreme rain (over 100 mm/hr) is even louder, and can generate an ambient bubble layer which will distort the recorded sound spectrum (Fig. 4).

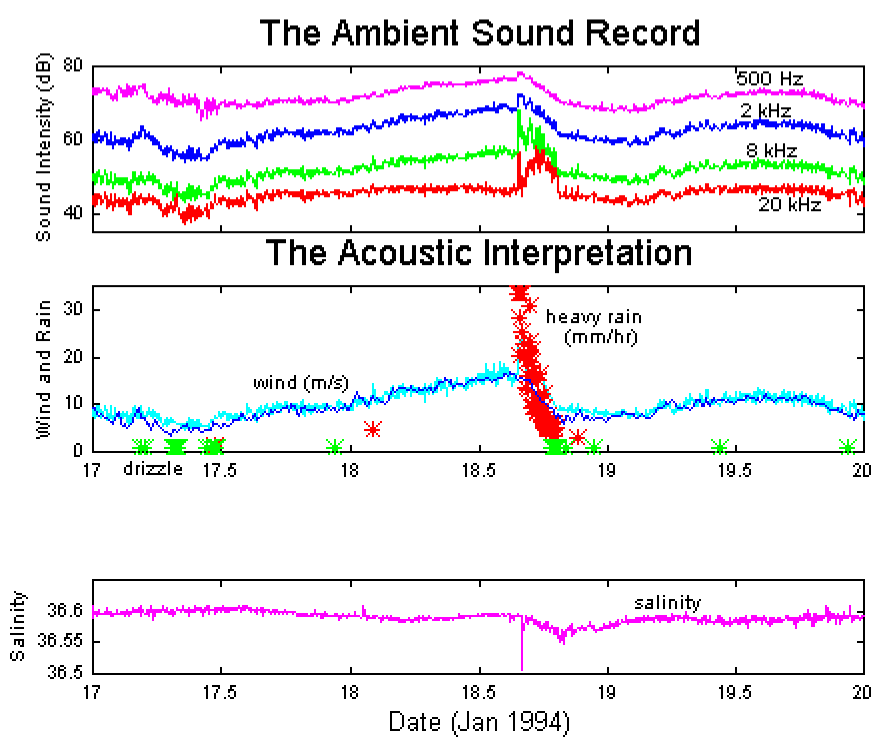

Figure 6. A temporal history of the sound field over three days at four different frequencies from the North Atlantic Ocean (ASREX Experiment, sponsored by Office of Naval Research). The lowest frequency (500 Hz) is not affected by precipitation, while the highest frequency (20 kHz) is affected by rain, drizzle and ambient bubbles. The acoustic interpretation of the sound record measures wind speed (cyan), rainfall rate (red) and detects drizzle (green). Comparison data for wind speed (blue) and near-surface salinity (magenta) from a nearby surface mooring are also shown.

An example of the acoustic interpretation of the underwater sound field is shown in Fig. 6. During this three day period a strong atmospheric front passed over the location of an ARG. When it was not raining, the acoustic estimate of wind speed matched a nearby mechanical anemometer to within ± 1 m/s (very good agreement). Because rain is so loud underwater, acoustical wind speed measurements are only possible when is not raining. During the peak of the storm, heavy rain was detected. This acoustic observation was "confirmed" by near-surface (1-m depth) salinity measurements. Similar records of acoustic measurement of rainfall have been obtained from ARGs on drifting buoys[11] and from an oceanic mooring in the South China Sea[12].

5. Conclusions

The sound of rain underwater is a loud and distinctive signal which can be used to detect and measure rain at sea. Individual raindrops make sound underwater by two distinct mechanisms: the impact of the raindrop onto the ocean surface and sound radiation from any bubbles trapped underwater during the splash. For most raindrops, the sound radiation by bubbles is, by far, the louder sound source. Because the geometry of their splashes regularly trap a bubble of uniform size, small raindrops (0.8-1.2 mm diameter) are unexpectedly loud underwater. These drops are responsible for the remarkably loud "sound of drizzle" heard between 13-25 kHz. Medium raindrops (1.2-2.0 mm diameter) are relatively quiet, while large (2.0-3.5 mm diameter) and very large (> 3.5 mm) raindrops have energetic splashes which can trap larger bubbles. These bubbles radiate sound at frequencies as low as 1 kHz. Because the different raindrop sizes produce sound with distinctive features, the sound field can be "inverted" to measure the raindrop size distribution within the rain. This is a good measure of rainfall rate, or other interesting features of rainfall.

Although there are sometimes man-made or biological noises which are loud and could potentially interfere with the acoustical measurement of rain, these noises are generally intermittent or geographically localized. When rain is present, the sound from rain dominates the underwater sound field. There are two features of rain and drizzle generated sound that allow detection of rain at sea. These are the relative level (very loud) and the relatively higher sound levels at higher frequency (over 10 kHz) when compared to wind. By monitoring for these distinctive spectral features, it is possible to detect and then quantify rainfall at sea.

New ARGs are currently being deployed on several of the moorings that form the Tropical Atmosphere Ocean (TAO) deep ocean mooring array deployed by NOAA in the tropical Pacific Ocean[13]. Data from these ARGs should become available for scientists beginning in the year 2000. By learning to listen to the ocean we can make important rainfall observations which will help meteorologists, oceanographers and climatologists to better understand the distribution and intensity of this important component of climate.

6. Acknowledgments

My father, Prof. John D. Nystuen, has had a pervasive and yet non-specific influence on my career. He inspired me to pursue an academic career. My most influential scientific colleague has been Prof. Herman Medwin from the Naval Postgraduate School, Monterey, California. Other key colleagues include my graduate and post-graduate advisors, Profs. Robert Stewart, Walter Munk and Dr. David Farmer. Long-term funding for my research has been from the Office of Naval Research - Ocean Acoustics (ONR Code OA321), but also from the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration - Pan-American Climate Studies (NOAA-PACS) and, most recently, the National Aeronautics and Space Administration - Tropical Rain Measuring Mission (NASA-TRMM).

7. References

1. S.P. Anderson, S.P., R.A.Weller and R. Lukas, 1996: Surface buoyancy forcing and the mixed layer of the western Pacific warm pool: Observations and 1-D model results. *J Climate* **9**, 3056-3085.

2. C.S. Clay and H. Medwin, 1977, *Acoustical Oceanography*, Chapter 6, Wiley, New York, 544p.

3. M. Minnaert, 1933: On musical air bubbles and the sounds of running water. *Philos. Mag.* **16,** 235-248.

4. H. Medwin, J.A. Nystuen, P.W. Jacobus, L.H. Ostwald and D.E. Synder, 1992: The anatomy of underwater rain noise. *J. Acoust. Soc. Am. 92*, 1613-1623.

5 .J.A. Nystuen, 1996: Acoustical rainfall analysis: Rainfall drop size distribution using the underwater sound field. *J. Acoust. Soc. Am.* **13**, 74-84.

6. H.C. Pumphrey, L.A. Crum and L. Bjorno, 1989: Underwater sound produced by individual drop impacts and rainfall. *J. Acoust. Soc. Am. 85*, 1518-1526.

7. S. Vagle, W.G. Large and D.M. Farmer, 1990: An evaluation of the WOTAN technique for inferring oceanic wind from underwater sound. *J. Atmos. and Ocean. Tech.* **7**, 576-595.

8. H. Medwin and M.M. Beaky, 1989: Bubble sources of the Knudsen sea noise spectrum. *J. Acoust. Soc. Am. 83*, 1124-1130.

9. D.M. Farmer and D.D. Lemon, 1984: The influence of bubbles on the ambient noise in the ocean at high wind speeds. *J. Phys. Oceanogr.* **14**, 1762-1778.

10. J.A. Nystuen and D.M. Farmer, 1989: Precipitation in the Canadian Atlantic Storms Program: Measurements of the Acoustic Signature. *Atmosphere-Ocean***27**, 237-257.

11. J.A. Nystuen and H.D. Selsor, 1997: Weather classification using passive acoustic drifters. *J. Atmos. and Oceanic Tech.*, **14**, 656-666.

12. J.A. Nystuen, M.J. McPhaden and H.P. Freitag 1999: Surface Measurements of Precipitation from an Ocean Mooring: The Underwater Acoustic Log from the South China Sea", submitted to *J. Applied Meteor*.

13. M.J. McPhaden, A.J. Busalacchi, R. Cheney, J.R. Donguy, K.S. Gage, D. Halpern, M. Ji, P. Julian, G. Meyers, G.T. Mitchum, P.P. Niiler, J. Picaut, R.W. Reynolds, N. Smith and K. Takeuchi, 1998: The Tropical Ocean-Global Atmosphere (TOGA) observing system: A decade of progress. *J. Geophys. Res,* **103**, 14,169-14,240.

Maps of Jackson, Mississippi

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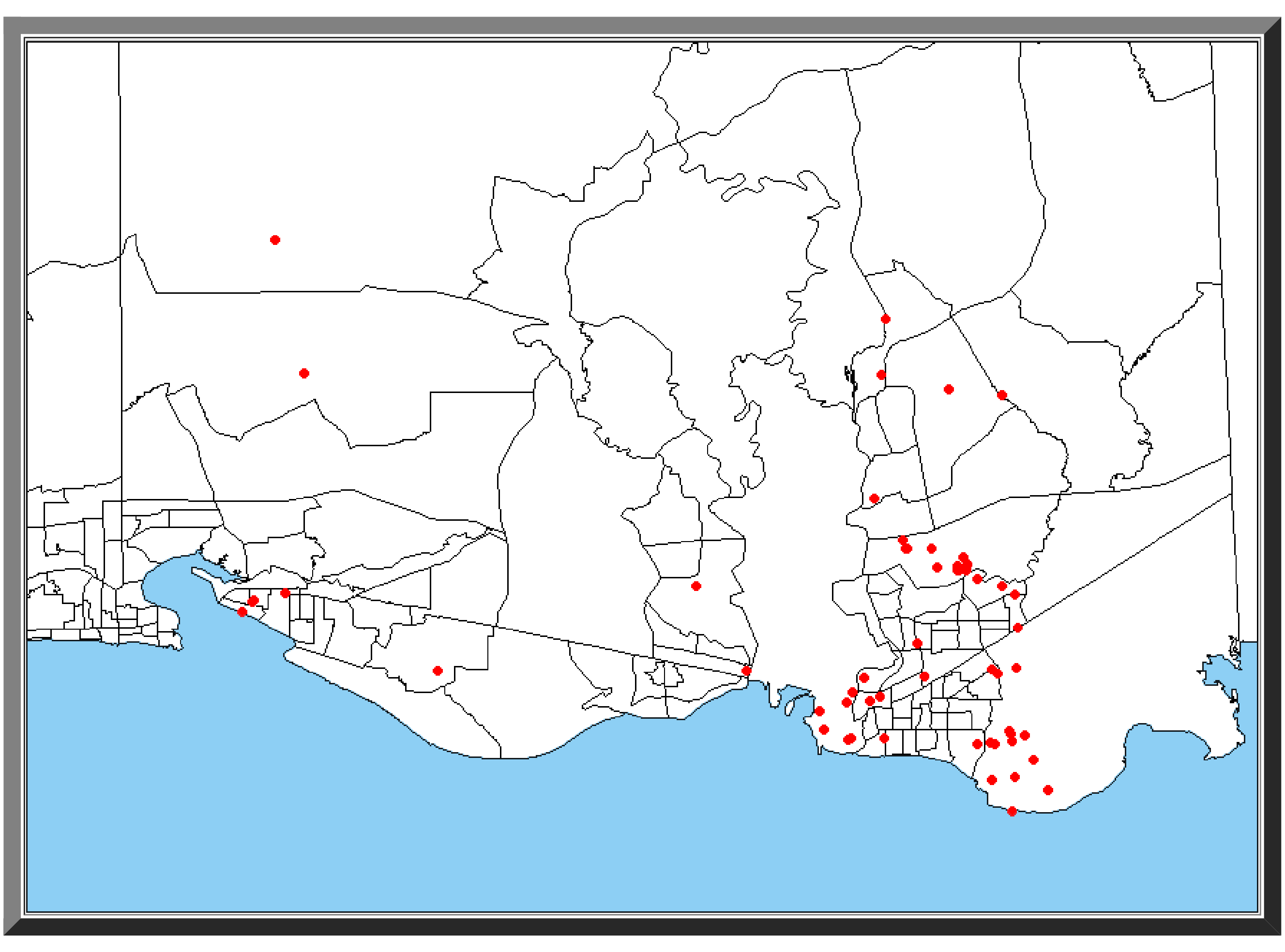
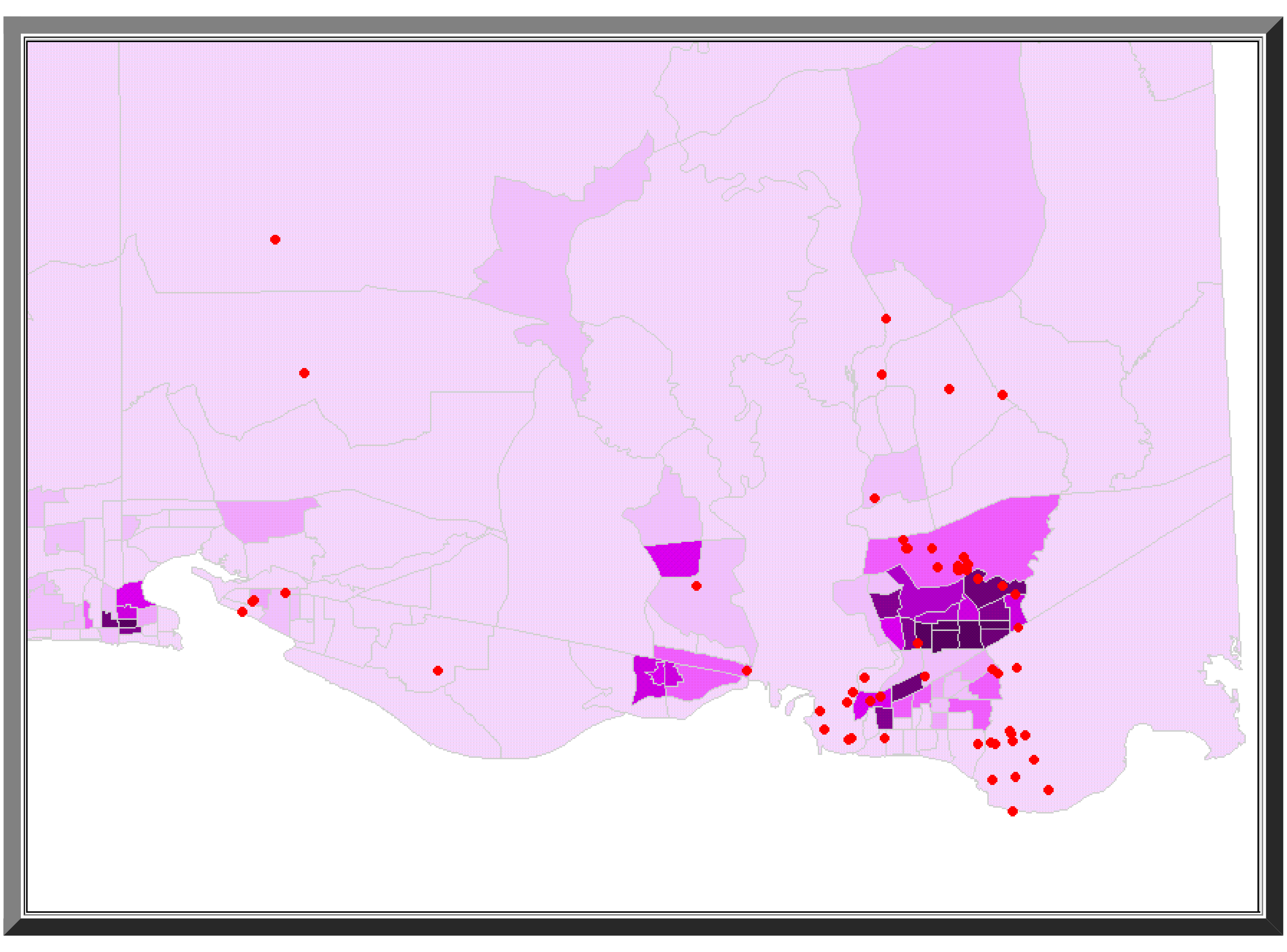
The Environmental Protection Agency (EPA) maintains an online mapping facility, called Landview III, that contains data and site locations for hazardous sites of various sorts, as well as selected Census, United States Geological Survey, and other, data and boundary files. The user visits the EPA site and is permitted to download, free, the Landview software and one county boundary file and one county data file (per transmission). For those, such as precollegiate teachers, this is a marvelous resource for gaining some mini-GIS mapping capability. For those with full GISs on their desks, Landview also serves as a fine source of location and data files. The data files come in .dbf format and many already contain positional information as decimal degrees of latitude and longitude. Thus the files map easily in, for example, ArcView 3.2 (Environmental Systems Research Institute--ESRI). Simply open the table of interest and open that as an Event Theme which can then be converted to a shape file. The maps below offer an example of this capability. In addition to Landview III, other software packages used were: ArcView 3.2 (ESRI), Spatial Analyst Extension (ESRI), 3D Analyst Extension (ESRI), Animal Movement Extension to ArcView (free), Adobe PhotoShop 5.5, Netscape Communicator 4.05, and MS Excel (Microsoft Office 97, Professional version) Windows 98 (Microsoft).

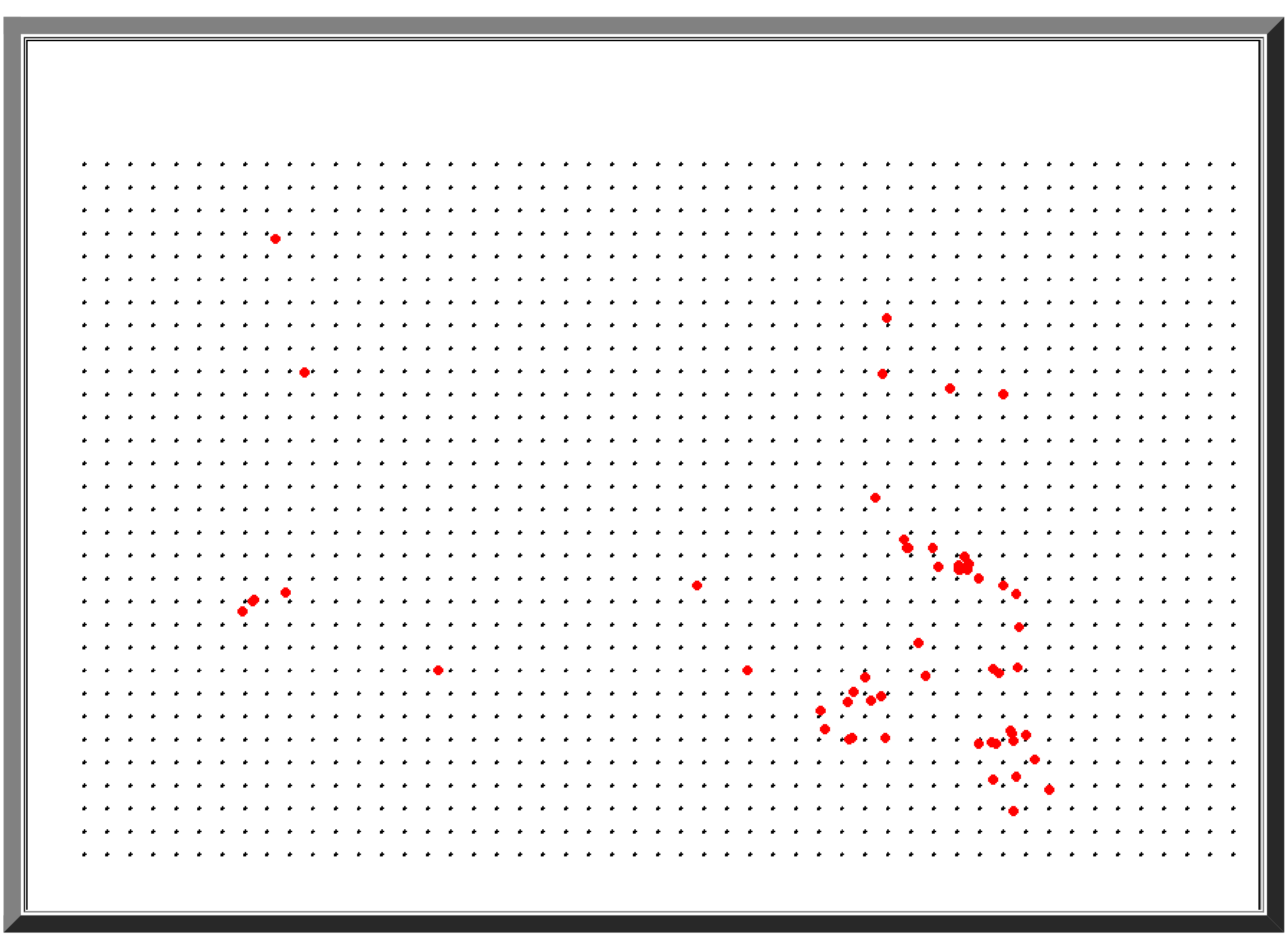
Map 1. In this map, all the EPA sites noted in the database (mapped as red dots) are treated equally. The files for each individual database were merged using the Geoprocessing Wizard extension in ArcView. The polygons are Census blockgroups. North is at the top of the map. The boundary on the east is the state line separating Mississippi from Alabama. Mobile, Alabama is just to the east. The Gulf of Mexico is to the south; Jackson is a coastal city.



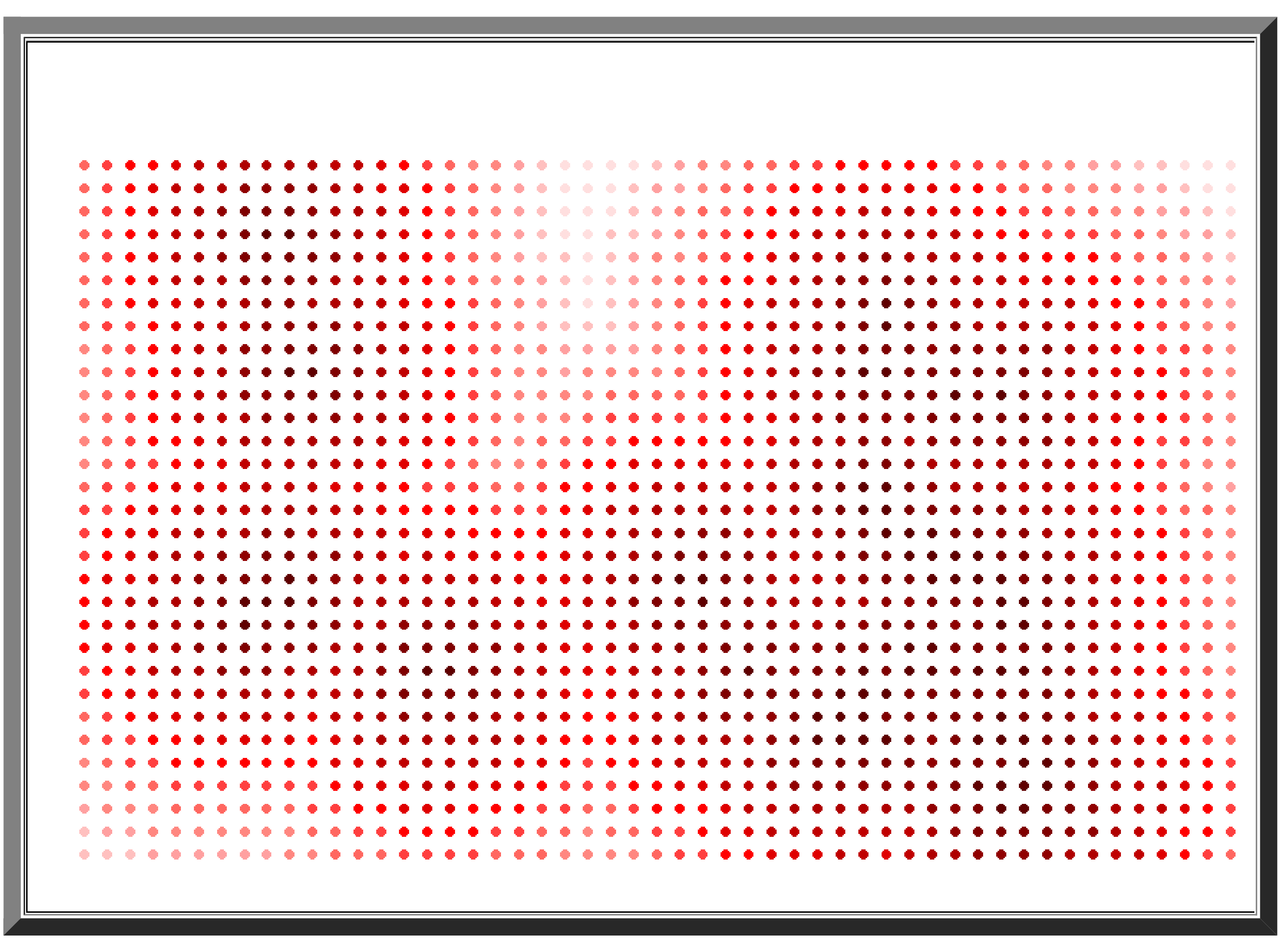
Map 2. A natural next step in the mapping process might be to create a thematic map using Census data for the blockgroups. One might consider demographics of various sorts in relation to EPA site location. The map below shows the blockgroup polygons colored by racial categories of "black" or African-American population and "white" or Caucasian-American population normalized by 1990 total population for each blockgroup. Deeper shades of purple indicate higher densities of African-American population. One direction that further mapping effort might take is to overlay other boundary files, such as rivers, and also to create more thematic maps based on other demographic, economic, and physical variables. The remaining maps suggest another approach.



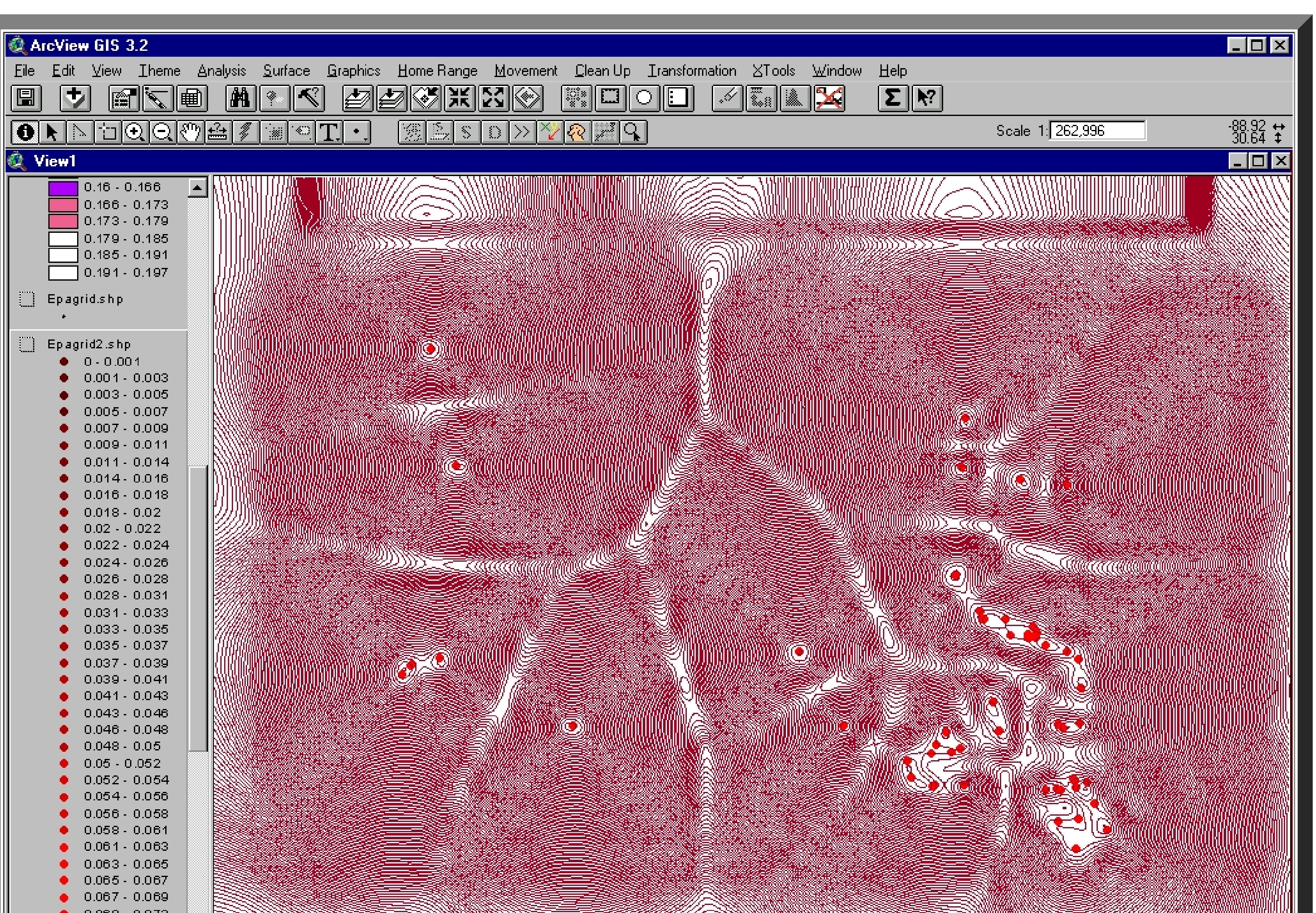
Map 3. The blockgroup boundaries were removed. A grid of points, spaced at 0.01 degrees of latitude and longitude was superimposed on the map. The grid database was created in Excel and brought into ArcView as an Event Theme.



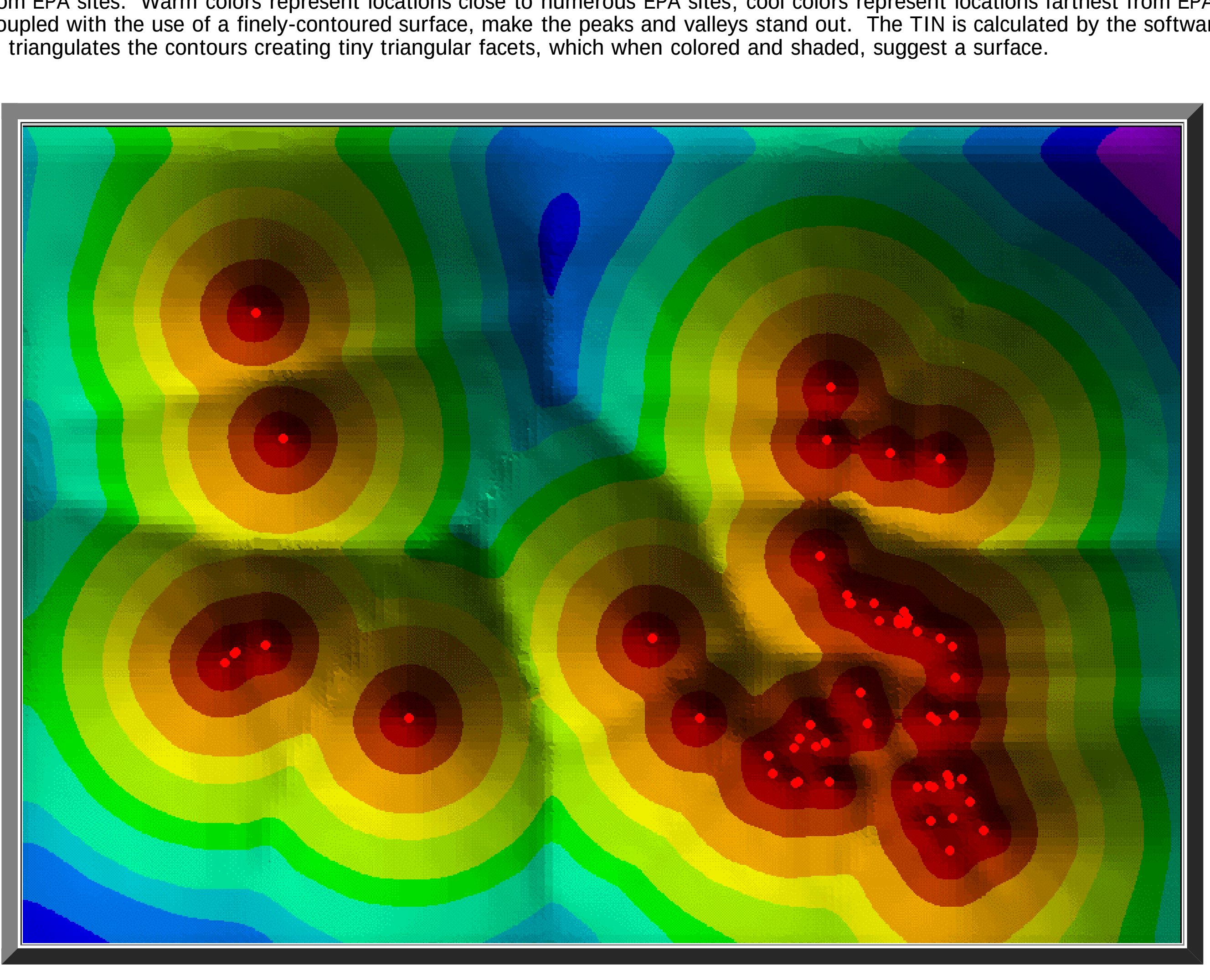
Map 4. The grid points were assigned weights based on distance from EPA sites. Those points closest were colored with the darkest shade of red; those farthest away with the lightest shade. The distances were calculated in Animal Movement Extension (Hooge and Eichenlaub, 1997), Movement|Calculate Distance, with distances measured from EPA sites to grid points. These distances were then used as weights and the grid points (as a shape file) were shaded using a standard color ramp. Weights might be assigned using any of a number of standard weighting techniques or using technique designed by the cartographer or other map creator (Tobler and Wineberg, c.1975 is one classic example).



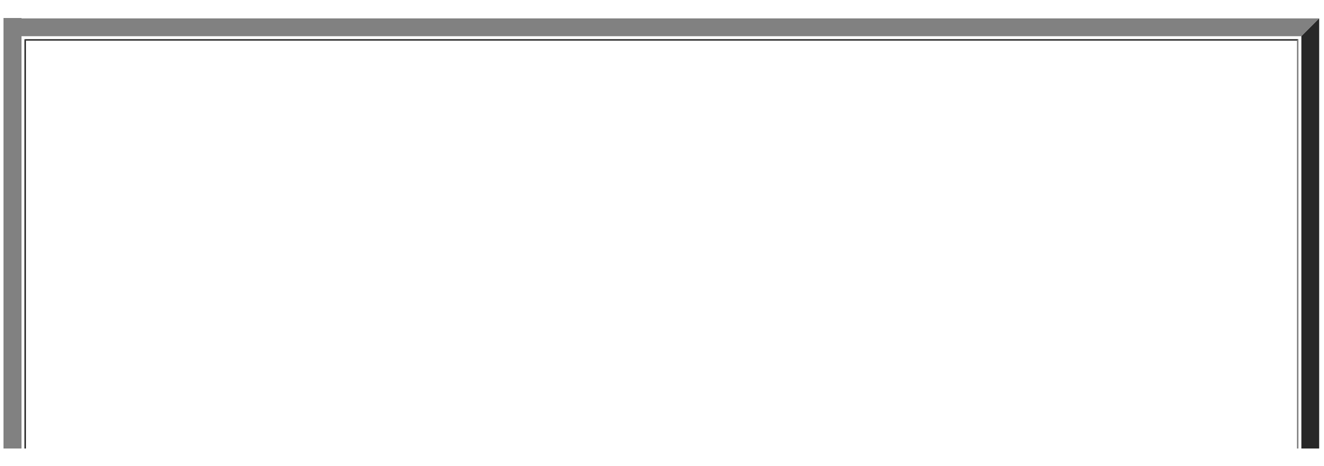
Map 5. The grid points were then finely contoured, in 0.001 parts of a unit. The Surface|Create Contours command was employed. The method of interpolation chosen was Spline, the Z-value used was the distance value calculated above, and the type of contour selected was a tension contour. Here the screen capture is placed directly from ArcView into the html file. Note the apparent swale lines and saddle points in the contouring representing troughs based on the distance data and peaks or flat surface surrounding the actual sites.

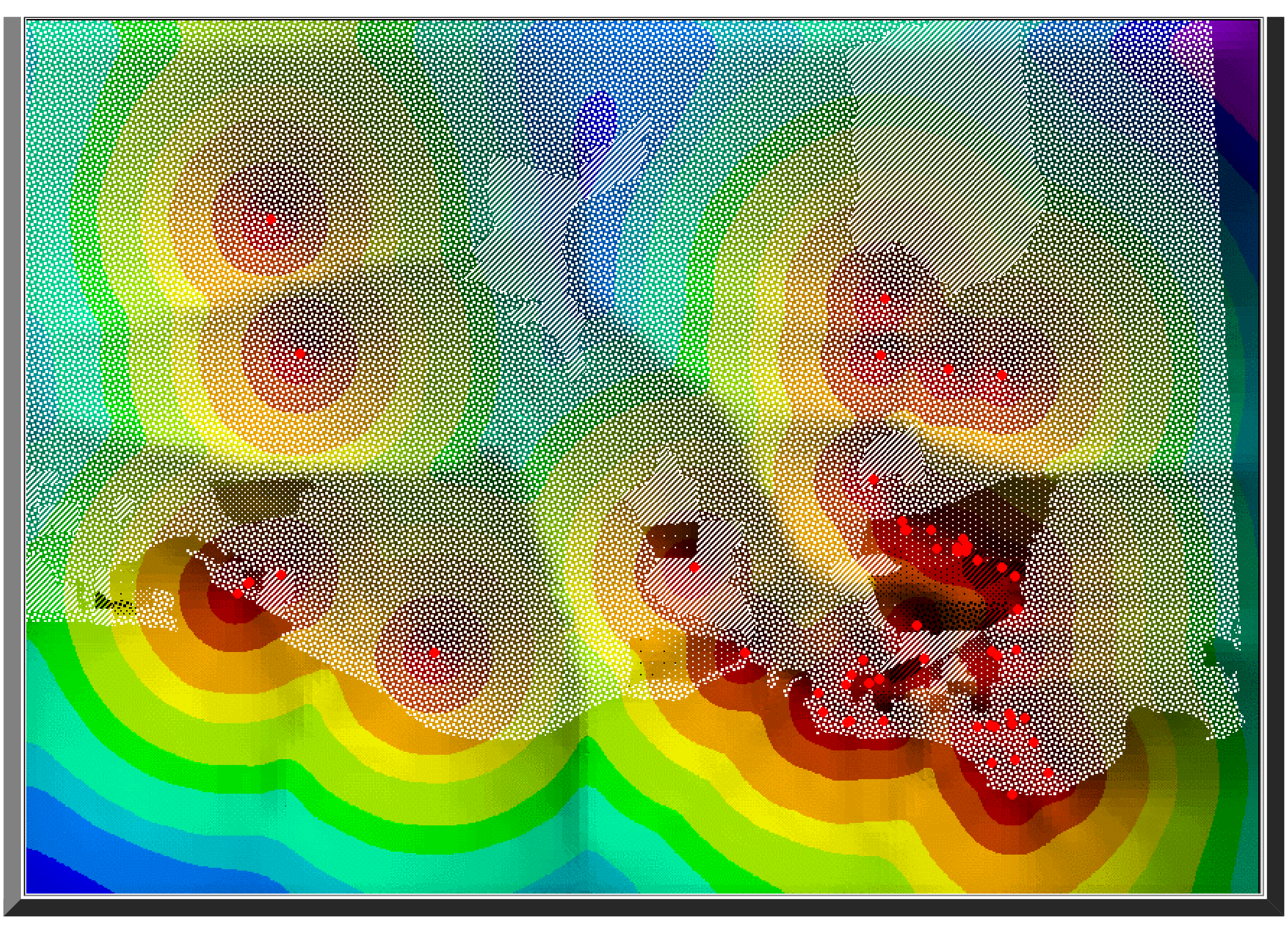


Map 6. The contours were then converted to a Triangulated Irregular Network (TIN) (Arlinghaus et al., 1994) to suggest a surface based on distance from EPA sites. Warm colors represent locations close to numerous EPA sites; cool colors represent locations farthest from EPA sites. Shading, coupled with the use of a finely-contoured surface, make the peaks and valleys stand out. The TIN is calculated by the software; basically, it triangulates the contours creating tiny triangular facets, which when colored and shaded, suggest a surface.



Map 7. The TIN is then covered with the thematic map shown in Map 2. Here, once again, the demographic data is calculated by block group: percent "black" and percent "white". Denser patterns of black and white represent greater block group densities of African-American and Caucasian-American populations. The block group boundaries were colored transparent as were the backgrounds behind the patterns so that the TIN would show through. To preserve the invisible background outside of ArcView, the Windows-universal screen capture, Alt+PrintScreen, was used to put a copy of the screen image on the Windows Clipboard. The clipboard was then pasted (Ctrl+v) into a blank canvas (File|New) in Adobe PhotoShop (which senses the size of the Clipboard image on opening a new blank canvas) where the image was cropped.





The evidence of maps can communicate information differently to different people. As mapping software becomes easier and easier to use, one can only hope that curricular matters keep pace. Maps like these in the hands of a policy maker can be helpful or dangerous weapons; fine geographic education can make them become the former.

References.

Arlinghaus, S. Austin, R., Arlinghaus, W., Drake, W., and Nystuen, J. Practical Handbook of Digital Mapping Terms and Concepts. CRC Press. 1994.

Hooge, P. N. and B. Eichenlaub. 1997. Animal movement extension to ArcView. ver. 1.1 and later. Alaska Biological Science Center, U.S. Geological Survey, Anchorage, AK, USA.

Tobler, W. R. and Wineberg, S. c.1975. A Cappadocian speculation. *Nature*.