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Developing Figures of Merit for Determining Relative Air Quality

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In spite of the fact that air quality has been a major national concern for many years measures have not been taken to develop a methodology for evaluating the relative merit of air quality alternatives. The research to be presented explores the issue of relative air quality merits and develops a rating approach to determine the superior alternative. These measures have been developed and tested using pollution dispersion models and accounting for spatial and temporal patterns of ambient pollution by means of a discrete network of receptor points.

1. INTRODUCTION

Air quality modeling has come to be an intrinsic part of the decision processes with respect to environmental effects. The Clean Air Act Amendments of 1977 required EPA to promulgate regulations specifying air quality models to be used in prevention of significant deterioration of air quality. The complexity of the processes of pollution dispersion led to the development of a large number of air quality models. The Environmental Protection Agency (EPA) has provided guidelines on some of these models and has indicated how EPA approved models are to be used in carrying out environmental calculations (EPA 1978). Legislation and regulations are couched in terms of concentration standards which are not to be exceeded more than once per year. There are difficulties and objectionable features to the use of such standards and to the use of the air models as the major means of fostering environmental health (Turner 1979) (Katzper and Ross 1981). However the decision making and modeling procedures are straightforward. For the most part the regulatory burden falls on new plants which must be built with expensive anti-pollution devices. In an attempt to reduce the costs of air pollution control and expedite the attainment of ambient standards EPA has permitted emissions trading. A corporation may reduce the emissions of an older unregulated plant and in return be allowed a less stringent emission level for its new plant. Such trading raises the problem of comparing the ambient air effect due to different plant configurations or different levels of emission. In this paper I present a proposed solution to this question.

2. BACKGROUND

The air quality indicies which have been developed and are in widespread use are not used for regulatory purposes. They generally are composite weighted linear functions of a select number of pollutants. Measurements are made of these pollutants. The values are substituted in the equation, and the air quality index value is reported. The problem of concern here is determining if air quality standards are violated in the course of a year. Later we will want to determine if a proposed trade represents an improvement or degradation in environmental quality. For the one hour standard we must have hour by hour data within the entire area for which the plants emissions have a noticeable effect. We must look at a multiplicity of spatial and temporal values. For regulatory purposes compliance with air quality standards involves the use of Gaussian dispersion models. EPA has made available a number of these models and accepts their results as a demonstration of compliance or non-compliance with air quality standards. Our focus will be on the short term, 24 hour standards for sulphur dioxide (SO2) and total suspended particulates (TSP). The law considers a plant to be in violation of standards if its emissions cause the second highest value found at any air pollution detector to exceed the ambient air quality standard value. For SO2 the 24 hour standard is 365 micrograms/meter3 . For TSP it is 150 micrograms/meter3.

One of the most widely used single source models is CRSTER, which calculates hour by hour, 24 hour and yearly average values for a grid of theoretical receptors. EPA modeling guidance suggests a minimum of 180 receptors. A grid configuration is likely to consist of 36 equidistant receptors in a ring with 5 succeeding larger rings. The CRSTER model run in this study provides hourly and 24 hour average values. For a 365 day year this is a calculation of 1,642,500 grid points. The maximum and second highest maximum values are found by this brute force simulation method and compared with the standards. If the second highest value exceeds the standard the plant is in violation. When trading of emissions was instituted the same criteria were followed initially.

There are a few motivations for this approach. For the non-technical person it provides a simple decision rule. It is intuitively appealing to believe that a few large values are indicators of overall high levels of pollution. By requiring that modeling be carried out with five years of suitable meteorological data there is some assurance that the environment will be protected under a large variety of commonly occurring natural conditions. There are known deficiencies in the use of dispersion modeling approaches (Turner 1979). From a general critical point of view it can be noted that the requirements are dependent on the unstable tail of a statistical distribution. Average values are not characterized at all. A few high values do not give an indication of the overall spatial-temporal characterization of air quality in an area. A plant may be in good compliance generally and the model may be picking up some abberant meteorological condition. Another problem is the fact known among air modelers that there is not a good correspondence between model predictions and experimental measurements of ambient air quality. It is interesting to note that these EPA approved models are not dispersion models in the sense that a physicist thinks of dispersion. Rather a Gaussian functional form is used with empirically determined parameters. It is this equation which is being evaluated at the large number of grid points. Be that as it may, the regulations and their focus on maximum or near maximum values provided a tool and a mind set. These inhibited further exploratory simulation research into broader characterizations of relative air quality.

3. DEVELOPMENT OF TRADING REGULATIONS

Costliness of air pollution prevention and a desire to use market like mechanisms to achieve cleaner air led to regulatory reform initiatives. A major initiative has been the application of the "bubble trade" concept. It is assumed, for a multi-plant site that a "bubble" is surrounding the site and it can be considered as one unit for regulatory purposes. In place of requiring specific control measures for the emissions of each plant the operators are allowed to "trade" emissions to achieve the same or better results more economically. Thus an old plant which is not legally required to may reduce emissions so that a new plant might be permitted to install economically optimal emission controls. Bubble applications to the EPA must demonstrate ambient "equivalence" or "enhancement"for approval. This sounds reasonable but the question arises as to how we can determine if "equivalence" or "enhancement" has been achieved. Our study has addressed this question as its central focus.

Regulations governing bubble trades have been evolving as experience with actual trades increases. Initial trades merely sought to ensure that air quality violations did not occur as a result of the proposed trades. For example the Green River Station trade followed the bubble policy of December 1979 (Federal Register 1979). Emission rates were reduced for smaller sources with shorter stacks and increased for larger sources with taller stacks. Running the models PTMPT and CRSTER "indicated no exceedances of ambient standards." (Federal Register 1981).

EPA wished to use bubble trades to reduce pollution levels rather than just ensure non-violation of standards. It therefore required that total emissions after a trade be less than or at most equal to pre-trade emissions. Under such conditions degradation of ambient air quality in some areas will still occur. Bubble applications, as a general principle, must demonstrate ambient "equivalence" by which term non-degradation is meant. Such equivalence demonstrations are made through dispersion modeling which predicts the ambient impact of extant or traded emissions. The Emissions Trading Policy Statement (Federal Register 1982) authorizes a three tiered application screen with the degree of modeling linked to the likely ambient impact of the proposed trade. Level I with relatively small trades requires no modeling. Level II involves modeling the effects of the proposed trade. If level II conditions are not met then level III requires full scale modeling of all sources impacting the area. To meet level II requirements the maximum ambient value of a pollutant for the year, under the proposed trade, must not exceede the maximum pre-trade value by more than a fixed threshold amount. EPA refers to this threshold amount as the significance level. The basis in law for this is that the administrator can specify the value at which quantities are considered too small to be taken into account as affecting the environment. For the 24 hour sulphur dioxide standard the significance level is presently set as 13 micrograms per cubic meter. Institution of the threshold level recognizes the large variability in ambient pollution due to meteorological and operating conditions. It is therefore undesireable to forbid a generally favorable trade which reduces emissions due to these fluctuations.

4. TEMPORAL-SPATIAL DELTA ANALYSIS

Policy is discussed and decided upon, even in issues with large technical components, by people whose knowledge is qualitative and obtained from secondary sources. Generally they do not seek to obtain the quantitative analysis needed to investigate a hypothesis they accept as valid. When involved quantitative information is presented many individuals without a quantitative background will have difficulty following the arguments. This leads to neglecting necessary information. Ironically, what is as dangerous is the intelligent person with a non-mathematical background who can follow the main lines of a technical argument and extract its essence and even utilize its conclusions. Appreciating the conceptual arguments but not the needed underlying analysis such an individual is as likely to accept an attractively presented fallacious argument as an argument based on extensive analysis. An occurrence of this sort appears to underlie the imposing of further unsuitable rules on trading. Most EPA air regulations (not necessarily appropriately or meritoriously) are based on worst case occurrences. Existing bubble policy similarly was formulated in terms of alleviating worst case occurrences. In reviewing bubble trade policy it was realized that there were differences between the base case and the proposed bubbles at almost all other times. The reasonable argument was advanced that the differences at all times and places must be looked at to protect the environment. The unwarrented conclusion was jumped to that if any difference was found greater than the threshold value then the proposed bubble trade was suspect. In such a case full scale modeling would be required before a trade was allowed. This conclusion was adopted as part of the regulatory framework without any analysis as to its correctness, significance or implications.

The approach described was honored with the title "temporal-spatial delta analysis." Faced with implementation of this scheme an EPA analyst created a hypothetical data set to demonstrate technical options. Four apparently equally legitimate ways were shown which could be used to calculate the demanded deltas. I generated a fifth legitimate approach. Results for the differences in this hypothetical data set ranged from 20 to 100 depending on the option used. Clearly what is needed is not a mechanical algorithm but a determination of what measures are the actual indicators of improvement in air quality.

The approach chosen was to use each receptor to obtain the day by day difference in concentration between the proposed alternative and the base case. The greatest of these differences is compared with the significance level and if it exceeds the significance level then full scale modeling is required. The typical number of receptors is 180. The resulting number of differences is 180x365, i.e. 65,700.

When the potential impact of this policy in eliminating trades was belatedly realized supporters of the bubble policy became justifyably concerned. Quite plainly there was a high likelyhood that emission reducing environmentally beneficial trades would be prevented by the policy that was adopted. Additionally, by the simple claim that any sensing of a higher level of pollution increases the likelihood of air quality standards violation the threshold concept was brought into question. An initiative was taken to lower or eliminate the threshold level. The counterargument that many more receptors were lowered than raised was discounted.

5. INITIATION OF SUBTANTIVE ANALYSIS

At this point a small project was initiated to study the actual implications of the regulations under which trades had been carried out. The study was to consider the effects on environmental quality of decisions based on threshold values and modeling procedures. A review and analysis of the initial justification for the setting of the significance levels was carried out. Available data from bubble trades where modeling was used was studied and the findings were reported. A simulation study using CRSTER was undertaken with a set of runs to try to relate the magnitude of the threshold level to changes that could be made in physical parameters. A literature search was made for related studies. Policy alternatives were explored.The theme, for me, in all this was to attempt to relate policy measures to indicators of environmental improvement or degradation and in this manner justify or invalidate the proposed policies.

Analysis,simulation and data studies all converged in their results to to show the need for consideration of area-wide effects as the appropriate measures of relative environmental quality. Furthermore it was shown to be feasible to design a simple averaging algorithm which can serve as a sensitive discriminator of relative air quality. Using such an index the environmental benefits of different trading proposals can be compared and rated.

6. DESIGN AND DEVELOPMENT

Redistribution of patterns of pollution will result from bubble trades. A series of these pattern changes have been studied using full scale simulation experiments. An inconvenient excess of data results. It is possible to eliminate large amounts of detail by focusing on the downwind concentration exclusively. This concentration profile will exhibit the major effects of concern in a given trade. For example, it is of interest to characterize the downwind concentration profiles in trades as a function of stack separation. A large number of partial simulations are not required to model these profiles. Downwind concentrations predicted by a simulation run with a moderately spaced grid can be taken and offset by various distances to give a combined source profile. This was done using published downwind values of simulation runs (Gschwandtner 1982). Results provided a quantitative demonstration in accord with our qualitative understanding. The redistribution with separation distances yielded higher values near the downwind origin but lower peak values. The outcome is a flattned distribution presenting less likelihood of violating standards.

These studies indicated how, for specific configurations, it is possible to determine the environmentally desireable outcome. It remained to construct a general index which would allow for comparisons in actual cases not reducable to the conditions of our simplified examples. As part of the effort to ensure that appropriate design criteria were incorporated in the index available simulation and monitoring data from actual bubble trades were reviewed. One focus was on the maximum increases (and reductions) from the base case to the proposed alternative. Another focus was on average measures such as the percentage of receptors where air quality improved and its average improvement, and the number deteriorating and the average deterioration.

Consideration of the regulations in conjunction with our studies led to the definition of a protective index which gives a measure of the extent to which the environment is protected against violation of standards. The protective value is defined as a function of the violation level minus the ambient concentration. A linear function is unsatisfactory as it will give equal ratings to averages based on uniform distributions of concentration as to nonuniform distributions. This difficulty is solved by defining the index in terms of geometric means. The equation for the index is : INDEX=EXP(Y) where Y= LN(X(i))/N . Summation is over all N concentration detectors. X(i) = Violation level - Concentration level of receptor i = V-C(i). Violations are not permitted so if C(i) > V then the protection index is defined as zero. The equation can be normalized to a 1 to 0 range. Applying the equation to a set of receptors with a fixed concentration sum for a variety of distributons of concentration values it can be shown that the uniform distribution gives the highest protective value. This satisfies our intuitive notion for the configuration which affords maximum environmental protection against violation of standards.

7. CONCLUSION

In spite of the availability of competent technical personnel at EPA they have not, to date, addressed the question of determining relative air quality. Neither is it dealt with in the literature. The results which have been obtained in this project can improve the environmental regulatory process and warrent further attention.

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