Research Response and Needs
(*What do we need to know?*)

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Smoke and Air Resource Management--Peering Through the Haze[1]

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Abstract: This paper presents a vision of the future rooted in consideration of the past 20 years in the smoke and air resource management field. This future is characterized by rapid technological development of computers for computation, communications, and remote sensing capabilities and of the possible societal responses to these advances. We discuss intellectual developments that we foresee and the likely manner in which these will be realized in the form of new tools available for air resource management. Finally we anticipate a changing climatic and political environment and we discuss the implications of this change on air resource management in general and on land management options associated with these changes in particular.

Fifteen years ago, the first microprocessors appeared for implementation in stand alone, single user, single process computers. Approximately 10 years ago, simple steady state Gaussian dispersion models were introduced as regulatory tools. The application of these regulatory approaches to smoke management from prescribed fire was foreseen in the Southern Forestry Smoke Management Guidebook (U.S.D.A Forest Service 1976) and applied in the USFS Smoke Management Screening System of the Forest Service, U.S. Department of Agriculture (1983). Finally, the first regulatory authority approved model, the Simple Approach Smoke Estimation Model (Bureau of Land Management 1987), appeared in Wyoming on Data General Desktops and microcomputers.[3] With the advent of the Bureau of Land Management Initial Attack Management system (IAMS) in 1985, fire managers were able to view map-compatible, real time graphic presentations of lightning strikes and weather information. During the next 15 years, the increasing power of the microcomputer will allow the development of integrated smoke dispersion modelling systems coupling fire emissions and behavior models, real time meteorological data, mesoscale terrain, wind field simulations, and dispersion trajectory analyses into desktop fire management tools.

The 1970 Clean Air Act introduced a conceptual basis for air resource management which has been refined and revalidated through subsequent amendments. The Act introduced the State Implementation Plan (SIP) to allow individual states to achieve federally mandated air quality goals in whatever manner they deemed most appropriate. The 1977 Amendments to the Clean Air Act maintained this posture and established the dual concepts that esthetics are

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[3]Mention of trade names and commercial enterprises or products are for information only. and do not imply endorsement by the sponsoring organizations.

deserving of protection (visibility) and that ecosystem health, not just human health, is to be protected. This protection, accomplished through the establishment of Class I and Class II areas, is implemented by federal land managers making decisions about the adversity of potential air pollution effects on the ecosystems they manage.

The next 15 years will probably not see much change in these current philosophies, but new environmental goals will be added. It is likely that the need for world-scale regulation will become obvious. In particular, we anticipate global CO_2/greenhouse gases ambient standards being put forth as a result of concerns about global climate change. By the year 2000 this standard will be one of a series of standards which will address not only global carbon balance but also the disposal and handling of toxic/nuclear wastes and other issues. At the very least, these standards will be voluntary on an international scale, but they will likely be mandatory in the developed industrial nations.

Population growth, especially in the Third World, is predicted to swell the world population to 6 billion by 2000. The 1 billion increase over the current world population is dramatic when played against the world population at the turn of the 19th century--l billion people. Although U.S. population will remain stable or decrease, the pressure of population increase will be felt everywhere. In particular, it will be experienced in the quality of the environment. A paradoxical fact will be that the amount of statutory wilderness in the United States will have grown continuously along with increasing world population and we will be among the world leadership in environmental protectionism. Increasing recognition or world public opinion related to strengthened world governmental structures will guide our environmental affairs.

What will the goals of U.S. smoke management be in 2000? They will be the same as they are today; namely, to manage the smoke generated from various types of prescribed fire to minimize its deleterious effects on the public. Biomass burning, however, will be considerably more controversial in 2000 than it is today. The demographic trends of increasing suburbanization and population growth in the South and the West established in the 1970's and 1980's will continue and be encouraged by decentralized office and work structures. Thus, "urban" people will be living in association with forests and hence smoke will cause, at least, the opportunity for increasing conflict.

REGULATORY CHANGES

While we will be dealing with regulations of toxic materials (discussed in some depth by D. Haddow at this conference) as well as continuing to be concerned about inhalable particles, the environmental issue of concern will be CO_2 and greenhouse gases. Since it is possible that in this time frame we will see movement away from a "carbon" based energy system (Barker 1987), it also seems that biomass burning will be heavily regulated. A likely result of the International Geosphere/Biosphere Program of research could be the verification that forest burning releases significant amounts of CO_2 and other greenhouse gases into the global atmosphere. Global CO_2 concentration increases will be, if not regulated, at least a major concern. Permits to consume biomass will be carefully allocated nationally and the need for precise smoke management will be present all over the contiguous United States. Forest burning might be among the only components of the global carbon cycle that can be manipulated. Thus, as a means of controlling CO_2 and greenhouse gas buildup, biomass burning could be heavily regulated.

Accentuating and underscoring the public life of all environmental issues will be the increased education level and increased international awareness of the general public. These factors will influence the political life of humankind toward attitudes even farther away from natural resource exploitation. The public will come to regard, more and more, that potential accentuation of global climate change through biomass burning is a morally unattractive activity. It will also regard the creation of a hazy or smokey atmosphere through particulate releases from prescribed fire as a signature of poor management. It will demand absolute minimums of smoke intrusions. The current laws in place in states like Oregon and Washington likely will be extended to other parts of the country. Smoke management and planning to avoid visibility impairment will be an integral part of the burning of forests, forest production wastes, and rangeland vegetation for management purposes.

MODEL DEVELOPMENT

Richardson (1965) was the first to consider that the atmosphere could be modeled by the solution of the equations of conservation of mass, momentum, and energy (hydrodynamic equations). The computation time, however, was a major limitation. Richardson estimated that if data on the state of the atmosphere could be made available within a few minutes to a room full of "computers," individuals with pencil and paper ready to calculate, the new state of the atmosphere could be calculated in an hour or so. It would only require 256,000 of these "computers"! In the early 1940's, John Von Neumann utilized the first digital computers to solve hydrodynamic equations. By the late 1940's and early 1950's, the first numerical models of global weather circulation were appearing. Owing to the quasi-two dimensionality of the atmosphere on a global scale as well as the overwhelming influence of certain low wave number instabilities, these computations were deceptively successful.

Weather prediction, using computer generated global circulation patterns, became operational in the 1960's. The quality of meteorological modelling has increased steadily ever since.

Since the popularization of computers in the 1960's, there has been increasing use of mathematical techniques to simulate natural behavior. While the general global circulation appears to be a very complex problem, and a laborious computation taxing even the most capable of super computers, it is a well posed mathematical and physical problem. There are no really fundamental problems, except the collection of data to drive the model, the parameterization of important physical processes like cloud formation, and the treatment of boundary conditions and "sub-grid" scales of motion, to implementation of global scale models. Increasingly we have been encouraged by the successes of computations on global atmospheric dynamics and have tried to venture forth in improving the boundary condition parameterization and "subgrid" scale representations.

All of these areas have proven to be major challenges to modelers. In general, they involve turbulent, three-dimensional motions. The turbulence problem is as yet unsolved; hence, any modelling involving turbulent flows must be of an approximate and heuristic nature. Turbulence is stochastic so that individual realizations of a flow field are uncertain and somewhat meaningless. The only predictive skill associated with turbulence comes about from ensemble averages and is only realistically characterized by wide variances and hence large uncertainties. Parameterization problems are largely associated with these difficulties as well as problems of scale. In the three-dimensional turbulence flow of the atmospheric boundary layer, the scales that should be resolved for a correct simulation range from $1x10^{-2}$ m to 10^{4} m, or six orders of magnitude! To conduct computations on a grid with 10^{6} resolution in each dimension would involve 10^{18} nodes. This is even beyond the capacity of super computers. Thus, any modelling done for the purpose of simulating atmospheric flows and their effect on the dispersion of smoke are going to be approximate and subject to large uncertainty. Also, it is very important to remember that because of the stochastic nature of atmospheric turbulence, individual realizations, that is trajectories of smoke from individual fires, will never be predicted with much skill. Any model will need to be verified by comparison with real flows and smoke plumes. The next 20 years of research into atmospheric turbulence should provide a much improved estimate of the degree of skill that might be achieved in predicting smoke behavior.

Modelling the dispersion of pollution in the atmosphere was originally attempted for military purposes and to support concerns about the distribution of radioactive materials in the atmosphere. These models were based on the assumption that the downwind distribution of contaminants could be approximated as a Gaussian distribution. The Gaussian parameters were modelled as functions of distance from the source and atmospheric stability. This development originated in the United Kingdom by Frank Pasquil and in the United States by Frank Gifford and has been in use ever since. Although computer advances have refined this basic concept, it remains the current approach for at least first order modelling. It is very likely this will still be the case in 2000.

The challenge of predicting pollutant dispersion for regulatory purposes started with the 1970 Clean Air Act which introduced the State Implementation Plan as an air management technique. SIP's required projections of the effectiveness of regulatory policies which, in turn, required the use of modelling. The 1977 Amendments specifically addressed modelling which required the Environmental Protection Agency, (EPA) to issue a modelling guideline and approve certain models for regulatory applications. All the models approved in the 1977 (first) edition and all those approved in the current (1986) edition of EPA's modelling guideline are Gaussian-based.

Associated with regulatory permitting problems in the late 1970's and early 1980's, a major effort was launched to understand and improve on the prediction of dispersion in complex terrain. This effort is still underway at this writing. It has led to the recognition of the role of atmospheric stability in complex terrain and the development of regulatory models which consider terrain in more or less simplistic ways. In the next 10 years, regulatory models with improved formulations that take advantage of this knowledge will be available and will greatly improve the prediction of concentrations in mountainous areas.

The major problem in predicting smoke dispersion in complex terrain will still be that of predicting the flow pattern. As stated earlier, this will remain a major complication. New super microcomputers will allow models such as the Topographic Air Pollution Analysis System (TAPAS) 3-D Wind Model (NUATMOS) to be applied at the user's desk. This will lead to an improvement in model ease of use, availability, physical presentation of results, resolution and mathematical sophistication. The problems that will remain will be:

--boundary conditions
--initial conditions
--turbulence and uncertainty
--topographic resolution.

Boundary conditions simulation will be a very active area of research, but its treatment will be a major limitation in the prediction of smoke dispersion. We will still in the year 2000, most likely, be parameterizing the surface energy balance in a very crude manner. The boundary condition problem will lead to difficulties in predicting transition flows and valley stagnation episodes.

Initial conditions will need not be a major problem, but the cost of properly generating them may be too high. Remote sensing instrumentation such as doppler radars and lidar systems, as well as the doppler acoustic sounder (probably considered as the old standby by the year 2000), will be available and linked to computers to initialize map compatible calculated windflows at isolated locations. These instruments will be costly and, although mobile based systems will be deployed for major prescribed fires, there will not be enough of them to go around. The initial condition sensing density will not be sufficient to do an optimum job.

Turbulence, as we stated earlier, is a cause of uncertainty in any consideration of the dispersion of pollutants. The problem is that ensemble behavior, that is the mean condition, provides only a rough indication of the specific realization that is either predicted or observed. Thus, no matter how well the mean condition is simulated or predicted, it will be imperfect and in some detail incorrect. This fact leads to the presence, in any calculation, of an inherent uncertainty. We are only now coming to accept this fact and to develop techniques that for example might calculate the inherent uncertainty and thereby provide the user of model results with a window of believeability. While this will be a major thrust of dispersion modeling in the coming years we will be slow to leave the relative comfort of our deterministic mind set. We expect to see the beginnings of a stochastically oriented approach toward smoke management by the year 2000.

Topographic resolution can be solved if we are able to pursue the current trend in Geographic Information Systems (GIS). To the extent the smoke management modelling can be coupled with such systems, the terrain resolution problem will cease.

In summary, we envision the smoke management model of 2000 to be not substantively different from the NUATMOS (3-D wind field) model currently within TAPAS. This will be coupled with a 3-D particle and cell type dispersion model which will be able to generate reasonable 3-dimensional dispersion patterns. Additionally, NUATMOS type models will be supplemented with a drainage flow generator based on a direct simulation of the energy balance at the earth surface and forest canopy. This drainage flow model will be capable of predicting the distribution of smoke released from the fire as partitioned between, within, and above the forest canopy component. In addtion [sic], we will be providing users with an estimate of model uncertainty as well as other results.

COMPUTER ADVANCES

In the early 1970's microcomputing as we know it today did not exist. About 1971, the INTEL Corporation released the 4004 microprocessor for a limited number of experimenters. This was a four bit microprocessor operating at less than 1 MHz clock speed. In about 1974 microcomputers appeared utilizing the INTEL 8800 processor; an eight bit device operating at 1 MHz or better. These microcomputers had 1 or 2 kilobytes (Kb) of random access memory (RAM) and used a punched paper tape for mass data storage. Paper tape as a mass storage device was soon (about 1976) replaced with cassette tapes for storage of data and programs.

In 1976 or thereabouts, a new era in microcomputers was starting. Apple Corporation released the Apple I (and soon after the II) which, it could be argued, did more to popularize the concept of personal computing than any other machine introduced before or since. The Apples (based on the 6502 processor) along with their Z80 based cousins, ushered in a period when users become both more involved with the small machines and more demanding in expectations for performance. Cassette tapes were soon discarded for floppy disk drives that held a whopping 64 Kb of data. RAM went from the 16 Kb size to 64 Kb with upgrades. The 64 Kb floppy disk was soon too small; users demanded more.

In response, the industry quickly changed its offerings. In 1979 the Apple II+, the Super Brain and various other eight bit, 2 to 4 MHz machines offered 64 Kb RAM and 160 Kb floppy disks standard. The CP/M operating system was in its heyday and new compilers and application programs were constantly being offered. In the period from 1979 to 1981 mass storage mania was soothed with the introduction of very expensive Winchester hard disks for microcomputers. In 1981 the IBM PC was born; a more or less true 16 bit microcomputer operating at a high enough clock speed, so that it was capable to handle and store enough data that scientists started to become both interested and addicted to small machines. Now, in 1987, true 32 bit machines with megabytes of RAM (proportedly gigabytes with the Apple Mac II) are emerging on the scene. These machines promise huge processing capabilities housed in an easily accessible user interaction environment.

By the year 2000 the microcomputer and its application software will dramatically improve from that available on today's newest 80386 or 68020 machines. This means that beyond a doubt the fire manager will have new power at his or her disposal to access fire emission data and meteorological data, and perform emission, dispersion, and air resource impact calculations.

TECHNOLOGY USER RELATIONSHIPS

Perhaps one of the most remarkable changes in understanding information has been the inclusion of simple graphics in integrated small computer programs. Nowadays, most good computer database and spreadsheet programs employ computer graphics. Computer graphics have become so pervasive that we take them for granted in all phases of data presentation.

By the year 2000 and beyond our expectations of appropriate graphic presentation of data will be drastically different. We will expect graphics to be interactive; one will be able to focus on specific pieces of graphic presentations and expand, reorient, or otherwise manipulate them to gain insights. For the smoke manager, this will mean three-dimensional presentations of smoke plume trajectories and concentration footprints that will be almost infinitely manipulatable. In addition, real time weather data could continuously be displayed and be used to adjust plume trajectory representations. These graphic representations will also be used to educate and inform the public as to the application of prescribed fire and its environmental impacts. The graphic representation of projected environmental impacts will become a common place tool for the land manager as current geographic information system software and data bases mature; the public will come to expect full graphical disclosure of land management information from its public land administrators.

Finally, the complexities of using these types of systems and large data bases will be moved farther and farther into the background of computer operating systems. By 2000, multitasking and parallel processing will allow implementations of expert systems that, utilizing artificial intelligence programming techniques, will allow fire managers to accomplish tasks of great complexity with minimum supervision. The hardware and software will not take care of themselves, but they will allow data collection, data analysis, and mathematical simulations to progress while the fire manager looks to other issues. Thus, a variety of constantly updated and improved information will be available to the fire manager, and perhaps the public also, at a moment's request.

CONCLUSIONS

Land managers are ecosystems managers. They are also technology managers. How well they will be perceived as managing both ecosystems and technology will rest largely on how well they assess the trends which will drive public opinions. We believe the next three decades. will be characterized by a growing public expression of global awareness and responsibility. The nuclear war issue will continue to influence this viewpoint, but global climate change may hammer out the interdependency of nations in the environmental sphere. We foresee the pattern of social trend as being toward international interdependence, cooperation, and ultimately international regulation.

IN THE YEAR 2000

Modelling of the dispersion and chemical interactions of fire released air contaminants will be a part of day-to-day fire management activities. First approximations of smoke impacts will still be most probably made using gaussian techniques modified for terrain influences. The major problem in predicting smoke dispersion will still be that of predicting three dimensional flow patterns. The increasing power of microcomputers will allow complex models, such as the TAPAS NUATMOS model coupled with an appropriate 3-D dispersion model, to be executed at the desk top. There will still be lack of skill in predicting actual smoke trajectories from individual fires, but users will come to understand estimates of model uncertainty along with other model results.

The gradual and inevitable spread of mass communications will foster the planetization of mankind's viewpoint. The increasing involvement of women and minorities in professional life will change the perception of dominance over the environment to one of stewardship and managing for diversity. In the end, but perhaps not by the year 2000, universal education will cause the fire manager to become subject to rules which will be international in scope and multigenerational in vantage. Technological improvements will serve this scope and vantage point, and allow both public review and involvement in smoke management process and activities on an almost real time basis.

REFERENCES

Barker, B. 1987. The world of 2006. Palto Alto, CA: Environmental Protection Agency Journal 11: 4-24; 1987 March 2. Environmental Protection Agency. 1986. Guideline on air quality models (draft). Research Triangle Park: Office of Planning and Standards.

Richardson, Lewis F. 1965. 1922 Weather prediction by numerical process. New York: Dover Publications; 236 p.

Riebau, A.R.; Fox, D.G.; Sestak, M.L.; Dailey, B.; Archer, S.F. 1987. Simple approach smoke estimation model (SASEM). U.S. Department of Interior. Bureau of Land Management. Unpublished draft supplied by author.

Turner, D. 1970. Workbook of atmospheric dispersion estimates. Research Triangle Park: EPA. Office of Air Programs Publication No. AP-26.

U.S. Department of Agriculture. Forest Service. 1976. Southern forestry smoke management guidebook. Gen. Tech. Rep. SE-10. Macon, GA: Southern Forest Fire Laboratory.

U.S. Department of Agriculture, Forest Service. 1983. Personal conversation with Lee Lavdas, Southern Forest Fire Laboratory, Macon, Ga.