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Project Summary

Strategies for the Development of Climate Scenarios for Impact Assessment: Phase 1 Final Report

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In order to create a strategy for the development of climate scenarios for use in impact assessment, potential techniques of development were reviewed and the information needs of potential users assessed. Available techniques were assessed through literature reviews and consultations with scenario development experts. Techniques were divided into ten modules, groups of techniques with similar methodologies, input requirements and output formats. Three modules involve approaches which model atmospheric processes, four concern analysis of past climate records, and three concentrate on methods for linking the other two. Each module can provide a scientifically well-founded piece of needed information, and a series of modules used together will produce the scenario. User needs were assessed in consultation with selected individuals who had experience in the use of scenarios. The major needs were revealed to be for general descriptive statistics of the major climatic elements, for information about climatic anomalies, notably drought, for statistics on the frequency and probability of events exceeding particular thresholds, and for general information about storminess. The results of the two sets of assessments are combined to provide a scenario development strategy. An iterative approach is recommended. Project areas incorporating both scenario development efforts and fundamental research are identified for the first three iterations.

This Project Summary was developed by EPA's Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The overall mission of the U.S. Environmental Protection Agency (EPA) Global Climate Change Research Plan is the assessment of the potential impacts of climate change on the environment, with particular emphasis on impacts in ecology, water resources, and air quality. A key element within this mission is the development of climate scenarios oriented toward the needs of those assessing these impacts. The goal for the current report is to provide recommendations and priorities for the development of techniques to produce impact oriented scenarios.

To meet this goal, the specific objectives are as follows: a) Identify all techniques potentially available for the development of scenarios; b) Identify user needs in areas where EPA is responsible for impact assessment; c) Assess appropriate techniques for impact-oriented scenario development, including assessment of current knowledge, level of effort needed, speed of potential development, needs of users, and suitability for transformation into routine scenario production techniques; d) Provide recommendations to EPA for the priorities for research, development, and production of impact-oriented climate scenarios.

A scenario is defined as: A suite of possible future climates, developed by using sound scientific principles, each being internally consistent, but none having a specific probability of occurrence attached.

This general definition applies to all elements of climate for any time in the future. However, to meet the EPA mission there are several requirements of scenarios:

- They must be tailored to user needs. Any scenarios produced must emphasize those climatic elements, time scales, space scales, and geographic regions of prime concern to those undertaking the impact assessment. In practical but general terms, regional scenarios, covering a specific geographical region, must be produced.
- They must be scientifically sound. The current state of the science is such that many assumptions must be included when any projection of future climate is made. Established scientific principles should be used whenever possible, so that the assumptions are reduced to a minimum. All assumptions should be tested using accepted scientific methods, their influence on the results evaluated, and their presence made explicit in any documentation associated with the scenario.
- They must be internally consistent. Any scenario which is produced must be based on the established physical and chemical laws controlling atmospheric and surface processes. Thus a scenario must not contravene these laws, which control not only the theoretical limits of variability of a single climatic element, but also the relationships between two or more elements and their temporal and spatial variability.
- They must provide a range of future conditions. A scenario is regarded here as a single estimate of the future climatic conditions. Since no deterministic forecast of the future is possible and no single scenario can be regarded as the "best estimate" of the future, a set of scenarios creating a range of possible futures must be produced. These may be developed from variations of the assumptions within a single scenario development method or by the use of alternative methods.

The concern that climate change may have an impact on human affairs is rather recent and there is a relatively small, but rapidly increasing, body of experience in development of scenarios. Some scenarios have been created primarily to assist in understanding climatic change, but the majority have been oriented towards the assessment of potential impacts. These include some general purpose scenarios designed to treat a variety of impacts and some more closely tailored to specific ones. However, no comprehensive review of possible approaches has included assessment of the strengths, weaknesses, and suitability for particular tasks of the various potential techniques. Such a review must be undertaken if appropriate, efficient, and effective scenarios are to be developed.

The users of these scenarios are those responsible for assessing the potential impacts of future climate changes. They also have little experience. Assessments are commonly undertaken using a model where statistics derived for the present climate are the input. This information is combined with information about the impact, and manipulated in various ways to yield an output relating climate variations to the specific impact. However, it is often difficult to disaggregate the model to identify those climatic elements and modes of variation which are most important, and therefore those elements whose emphasis in future scenarios is most important. Thus, users have had varying degrees of success with the presently available scenarios. The initial experience, however, provides insights into the real information needs of users, experience which is assessed here as an important element in the production of user-oriented scenarios.

Combining both the user needs and the scenario development possibilities, potentially fruitful lines of research into methods of scenario development can be identified. By including consideration of the development effort required, probability of success, and the potential for transforming the method from a research tool to an operational technique, it is possible to develop priorities and recommendations for scenario research.

This review provides a theoretical framework upon which practical experience of scenario development must be built. Current knowledge, along with the value of the experience likely to accrue from creating and using scenarios, dictates that an iterative approach to development be used. Scenarios are developed by climatologists in cooperation with users and tested by those users. Refinements can be incorporated as a result of both the user evaluation and the ongoing scenario research. Over several iterations scientifically sound, readily usable, and clearly documented scenarios can be produced for routine use in impact assessment.

Research Needs

Programmatic Needs

In developing such a strategy, there are two major considerations:

1. The need to develop some scenarios in the near-term.

As part of the overall scheme of the EPA Global Climate Change Research Plan, and as the explicit strategy adopted here, an iterative approach to scenario development must be used. As such, it is necessary to produce some scenarios in the near-term which can be provided to those assessing impacts. Although these must contain the best and most pertinent information possible, an equal focus is on assessing the user's "reaction" to the nature and quality of the scenario which is provided. This information can then be used in the next iteration to produce a new set of scenarios which are both more scientifically sound and more appropriate for the user.

2. The need to support research designed to develop, in the long-term, more scientifically sound scenarios.

New methods of scenario development must be explored in an explicitly research mode. A variety of efforts, involving several modules, and with varying levels of immediate relevance to scenario development, must be fostered. Both user needs and scientific credibility must be considered. It is anticipated that the results of this type of research, as they become available, will be incorporated into the subsequent generations of scenarios. Although EPA has a specific, mandated role in the production of assessments of impacts of potential climatic changes, and specific research strengths because of its traditional mission, it is not operating in isolation. A considerable body of research, from a variety of perspectives, is being undertaken or sponsored by several international bodies, government agencies and private groups. EPA must be cognizant of this work, both to avoid unnecessary duplication and to seize opportunities to use legitimate research results, where appropriate, in the further development of scientifically sound scenarios.

Scenario Development Methods

Three basic types of scenario methods were identified: Process Models, Empirical Methods and Linkage Techniques. The first two arise because of the fundamental division in the type of climatic information available for scenario production. The process models attempt to use the underlying physical laws of atmospheric processes to deduce climate under changed conditions. The empirical approaches use the records of past climate to indicate possible future conditions. Both approaches have strengths and weaknesses (Table 1). A consensus is emerging that process models must form the basis of any scenario because they provide the only means for explicitly estimating climate in changed atmospheric conditions. At present, however, such models cannot provide the spatial and temporal detail needed for the provision of user-oriented scenarios. Hence, they must be linked to empirical methods if useful scenarios are to be produced (Table 2). Although the importance of this linkage may decrease as the process models become more sophisticated, detailed, and reliable, it is clear that they will be needed well into the foreseeable future. Methods of establishing these links provide the third major group of scenario modules.

The process models strive to use the laws governing atmospheric processes to understand the present conditions and estimate future ones when boundary conditions are changed. There are numerous possible approaches to process modeling. The major division is based on spatial scale. Different modeling techniques, having different input requirements and output products, are used for each scale.

Process models include both "physical" and "chemical" models. The former are emphasized here, being more directly related to the elements normally regarded as climatic. Nevertheless, chemical models are designed for air quality assessments, and thus people using them constitute one group of users for whom scenarios must be designed. Nevertheless, chemical activity in the atmosphere can have a major influence on the climate itself, and there are important links between chemistry and climate at all scales.

Within the empirical techniques category are analyses of past conditions, whether the instrumental record of the past few decades, historical sources for the past few centuries, or the paleoclimatic reconstructions of past millennia. The strength of these approaches is that many of the techniques are well established and can provide a great amount of detail derived from actual, known occurrences. The prime drawbacks are that the physical causes of future climate conditions may be different from those of the past, and so the future conditions may be outside the past range of observed situations.

The above discussion indicates that few of the modules, either process or empirical, can stand alone as scenario production techniques. There must be linkage between them. The most desirable linkage is one whereby the output of one module feeds directly into the subsequent one. For such links the modules must have appropriate types of outputs and inputs. In many cases this mainly involves a matching of temporal and spatial scales. Consideration of the potential for such links should be encouraged during module development. At present, however, few direct links can be established and other linkage techniques must be used.

Table 1. The Major Strengths and Weaknesses of the Process and Empirical Approaches to Scenario Development

Strength	*Weakness*
Process Models	
Explicitly incorporate many atmospheric processes	*Coarse temporal and spatial resolution*
Directly include changed atmospheric composition	*Few elements estimated with any confidence*
Empirical Methods	
Provide great temporal and spatial resolution for many regions	*Cannot readily consider changed atmospheric composition*
Many elements available	*Processes deduced only by inference*

Table 2. The Potential Scenario Development Modules

Global Models
- *General Circulation Models*
- *Global Chemical Models*

Regional Models
- *Numerical Weather Prediction Models*
- *Regional Climate Models*
- *Regional Chemistry Models*

Local Models
- *Mesoscale Meteorological Models*
- *Urban Chemistry Models*
- *Surface Boundary Models*

Analogue Techniques
- *Instrumental Analogues*
- *Proxy Analogues*
- *Spatial Shifts*

Circulation Analysis
- *Circulation Indices*
- *Teleconnections*

Climatological Statistics
- *Mean Statistics*
- *Event Statistics*
- *Temporal Statistics*

Synoptic Analysis
- *Statistical Synoptics*
- *Spatial Synoptics*

Linkage Techniques

Adjustment Methods
- *Statistical Adjustments*
- *Spatial Adjustment*

Transfer Function Methods
- *Statistical Transfers*
- *Process Transfers*

Synthetic Methods

There is relatively little experience in the creation of linkage modules and no methods are well established. Indeed, this is an area of research which has itself been stimulated by the need for scenario development. Nevertheless, several lines of approach can be suggested within the modular context. They must, in most cases, be speculative, and indicate general lines of approach rather than refer to already well-established techniques.

User Needs Assessment

The second major piece of information required for scenario development is specification of the climatic information needs of those undertaking impact assessments. The impacts involve a variety of disciplines, including water resources, ecology, air quality, and agricultural production. Therefore, a wide variety of needs could be anticipated. However, for this analysis the requirement is for the identification of the major types of needs, expressed in a form which allows them to be linked with the possible scenario development approaches identified in the preceding section. Although some indications of such needs can be obtained from the published literature it was deemed most advisable to assess them in direct cooperation with people having experience with impact assessment.

We asked for a priority list of climatic elements that the users would like to have in future scenarios. Table 3 gives a list of those variables, with the percentage of the total number of responses that asked for that variable. Most respondents listed a number of factors, some only a few. Other variables, not listed in Table 3, that were mentioned more than once included mixing depth, evaporation, growing season, storms, and glaciation.

Other user needs are summarized to identify major needs for climatic information (Table 4).

A time scale of one day will, with the exception of the unusual events, satisfy most of the user needs. The daily values must, however, be capable of producing a time average allowing for simpler scenarios for those who require them. Shorter time scales and unusual statistics may be needed by only a small minority of users.

Spatial scale requests were much more variable, but it seems that a goal of a 100-km grid would satisfy most users. However, variables such as convective rainfall and orographic effects will certainly not be represented in this grid, and are needed in many important cases, so some accommodation will be necessary for these cases.

The response to questions about the actual climatic information needed allows the division of the information needs into four broad categories (Table 4). In large measure these reflect current experience with scenario use. The first of these can at this time be specified in some detail, the others, in many cases, will require extensive research to be able to be produced.

Conclusions and Recommendations

This project assessed the information needs of potential users of climate scenarios, the methods available to develop scenarios, and strategies for research to develop scientifically credible impact-oriented scenarios.

User needs were ascertained through consultation with people having some experience with scenario use. The major needs are:

Table 3. Climate Element Needs of Impact Assessors

Variable	*Percent of Respondents*
Temperature	*90*
Precipitation	*81*
Wind	*52*
Radiation	*48*
Water Vapor	*48*
Clouds	*29*
Snow	*20*
Pressure	*10*

Table 4. Summary of Major User Needs Identified from Discussions with Scenario Users

Time Scale
Daily values - not necessarily a sequence of daily weather

Space Scale
100-km x 100-km grid-specific needs highly variable

Information Needed

1. *Simple descriptive statistics for individual elements (means and variance, totals, extremes, etc)*
2. *Climatic anomaly information, especially concerning drought (magnitude and persistence of events)*
3. *Threshold values (probability of values significant for particular impact)*
4. *Synoptic information, especially for storms (sequences of events and combinations of elements)*

- Simple descriptive statistics for individual climatic elements.
- Climate anomaly information, especially concerning drought.
- Information about the frequency and probability of occurrence of various threshold values.
- Synoptic information, especially concerning storms.

Potential scenario development methods were identified through literature reviews and consultations with people having experience in scenario development. It was recognized that currently available scenarios are primitive and may be misleading, but that techniques are already available to produce more scientifically sound ones.

From these investigations, it is recommended that a modular approach to scenario development be adopted. Each module consists of a set of related analysis techniques which are themselves well established and tested, and which can be used to provide pieces of information required for scenarios. Linkage and combination of modules allows the development of a complete scenario.

Ten modules were identified. Three involve process models which use the laws of chemistry and physics to provide understanding of the processes acting to control climate, and thus can be used directly to investigate climatic changes resulting from the greenhouse effect. Included with these are the General Circulation Models which provide the main basis for development of scenarios. Four modules incorporate empirical techniques for scenario development, which use the records of past climatic conditions to provide indications of the nature of climatic variations on the local time and space scales needed for most impact assessment. The final three modules are linkage techniques designed to allow combination of the other modules to provide the required scenarios.

The techniques in each of these modules are at various stages of development. Some can be used directly for scenario production while for others a major research effort is needed before they can be used. For almost all of them, their suitability as scenario production techniques has yet to be tested.

Because of the various levels of development of the modules, and given the overall lack of experience with scenario development, it is recommended that an iterative approach to scenario development be adopted. For each phase a set of scenarios are produced and used for the assessment of a particular impact. Thereafter the scenario is assessed for its scientific credibility and its value for impact assessment. Appropriate modifications and refinements are made and a new scenario produced to start the next iteration.

Three phases of iteration are recommended here, covering the short-term (1-2 years), the medium-term (3-4 years), and the long-term (more than 4 years). Within each phase, three types of projects are recommended:

- Scenario development
  The actual production of scenarios which can be provided to the users for impact assessment.
- Module research
  Investigations aimed at refining the techniques within modules to produce more soundly based scenarios.
- Ancillary activities
  Projects designed to ensure that any scenarios produced are responsive to user needs and can be routinely and easily used in impact assessment.

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The complete report, entitled "Strategies for the Development of Climate Scenarios for Impact Assessment," (Order No. PB 90-192 022/AS; Cost: $17.00, subject to change) will be available only from:
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