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Project Summary

Temperature Scenario Development Using Regression Methods

Peter J. Robinson

A method of developing scenarios of future temperature conditions resulting from climatic change is presented. The method is straightforward and can be used to provide information about daily temperature variations and diurnal ranges, monthly average high and low temperatures, and the frequency with which user-selected high- and low-temperature thresholds are crossed. Linear regressions between monthly average temperature and these various attributes are established by using the observational record of daily maximum and minimum temperature. These regressions are then used to estimate values from the monthly average temperatures estimated by General Circulation Models to occur as a result of a doubling of atmospheric CO_2. Values can be established for any location having daily temperature records. For the United States the station density is sufficient to allow the creation of detailed regional scenarios on the spatial and temporal scales required for impact assessment. The assumptions, scientific and statistical, inherent in this regression-based approach are reviewed. The method has been incorporated in a self-contained PC-based computer program requiring only the actual temperature data to be input by the user. A demonstration of the use of the program, incorporating discussion of techniques for evaluating the quality of the resultant scenario, is provided.

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

Concern about the potential impacts of climatic change on the environment and on human activities has created the need for estimates of future climatic conditions. Since it is not possible to produce "forecasts" analogous to daily weather forecasts, it is necessary to suggest future conditions in terms of scenarios. A climate scenario is a possible future condition, but because many assumptions must be used in scenario development, no single scenario can give a definitive prediction of the future. Hence sets of scenarios, each developed on sound scientific principles but with no definable probability of occurrence attached, are usually produced to indicate the likely range of possible future conditions. This set of scenarios must contain sufficient details for assessment of possible impacts of climatic changes. Such assessments could be used by decision makers to develop strategies to meet the challenge and opportunities posed by climatic change.

Most impact-related scenario development in the past has been undertaken by a trained climatologist in close association with those responsible for assessing the impacts. As the need for and number of such assessments increases, however, the involvement of a climatologist cannot be guaranteed. Consequently, methods must be developed that the impact assessors themselves can use to create and interpret scenarios. Care must be taken to ensure that the development and evaluation of the resulting scenario leads to scientifically justifiable conclusions. Because no single scenario development technique will meet all impact assessment needs, a variety of ap-

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proaches must be made available. This study, with the associated software, provides a method of assessing *local* temperature changes associated with *global* climatic change. The scenario program that is described and documented, TEMPSCEN, is the first program designed specifically to allow non-climatologists to develop scenarios for their own needs in their own local areas.

The program discussed in the present document creates scenarios of future temperature conditions for any stations in the United States having four or more years of daily maximum and minimum temperature observations. The scenarios are for a time when the atmospheric concentration of greenhouse gases has doubled, currently estimated to occur sometime towards the middle of the next century. Regression relationships are developed between monthly average temperature and various temperature attributes from observational data which are provided by the user. These relationships are then used to estimate new values of the attributes in the monthly average temperatures postulated for the future by general circulation models (GCMs). Modeled temperatures from four different GCMs are provided as part of the program package. At each stage of scenario development, opportunities are provided to assess the strength of the various relationships and thus the validity and reliability of the resulting scenarios.

The temperature conditions, called temperature attributes, considered are the following.

- monthly standard deviation of daily temperature
- monthly average diurnal temperature range
- monthly mean of daily maximum temperature
- monthly mean of daily minimum temperature
- number of days in the month with maximum temperature above a user-selected threshold
- number of days in the month with minimum temperature below a user-selected threshold

The scenario development program itself is a personal computer-based software program; it is menu driven and largely self-explanatory. The project final report is designed to be used in conjunction with that software. It provides the rationale for choosing a particular scenario development technique, and an assessment of the scientific problems associated with the one selected. Information on installation and use is given. A scenario development example is shown. This example is presented in detail, placing the somewhat theoretical concerns considered earlier into a practical context. It provides the information necessary to ensure that the technique is used correctly from the scientific and climatological perspective, so that valid conclusions can be drawn.

Climate Scenarios

To meet the overall objective of producing a scenario development technique which could be used legitimately by impact assessors without outside assistance, the technique had to

- meet the user's need for specific information,
- be capable of use and evaluation by non-climatologists,
- use easily understood and scientifically sound techniques,
- use readily available data,
- be applicable to any region of the USA,
- be widely and readily available.

The technique was developed as a PC-based computer program. In this form it can be made widely and readily available. Further, a variety of U.S. climatic data are already available in PC-compatible format. The program is self-contained, needing only the temperature data of the area of interest as input. Included in the program are procedures for assessing the scientific validity of the results. The project report amplifies and explains these procedures, so that the program and documentation together ensure that the resulting scenario can be correctly developed and wisely interpreted.

Development Options

Selection of the specific need to be addressed was based on the results of an earlier assessment of the strategies for scenario development. That study showed that those involved in impact assessments had a clear need for scenarios on local (100 km) spatial scales containing information on the frequency with which specific temperature thresholds were exceeded.

Even with this well-defined need, there are many possible scenario development approaches. Most of these approaches were assessed for their ability to meet each of the program constraints indicated above. The most suitable was deemed to be a method using historical observational records to develop a regression relationship between the number of threshold crossings and monthly average temperature. This relationship could then be used with GCM-based estimates of future monthly average temperatures to determine the frequency of threshold crossings in the changed climate.

The technique used in this approach is linear regression, a technique almost certainly familiar to anyone undertaking an impact assessment. Correlation coefficients and significance levels for the relationship are given, and thus the user is able to make judgments about the quality of the resulting scenario. Further, the user is also likely to be in a position to understand the scientific basis for the method and the scientific uncertainty associated with its use. Study of many other nonlinear regression techniques failed to show that any of them offered significant improvement over the simple linear model.

The only data required of the method are daily maximum and minimum temperatures for the stations in the area of interest and the GCM estimates of future temperatures in that area. These data are available for any region of the world. The current version of the program is restricted to analysis in the United States. The appropriate GCM data are provided as part of the program package. The daily temperature data are widely available in a number of forms. The program is tailored to use temperature data downloaded from optical disks directly, but other formats can be accepted, although they may need some off-line formatting.

The program and method were designed to emphasize the development of scenarios for temperature threshold crossings, since this meets a well defined need in impact assessment. However, the method allows calculation of a variety of other temperature attributes. The attributes were chosen as a mixture of those having application in impact assessment and those useful for exploring the validity of the method and the character of future climates. The attributes calculated, with suggestions of their role, are as follows.

1. Standard deviation of daily temperature within month:

   This explores, within the limits of the method, the way in which the day-to-day variability of temperature changes as the mean temperature changes. There are indications for some areas that the variability decreases as the mean temperature increases. The variability may give clues to the type of synoptic weather changes likely under a changed climate.

2. Monthly average diurnal temperature range:

   This explores how the monthly mean daily temperature range varies as a function of monthly mean temperature. Present GCMs suggest that the green-

house effect should influence minimum temperatures more than maximum, so that if this method indicates a decreasing diurnal range with increasing mean temperature, it suggests a degree of realism in the scenario.

3. Monthly mean of daily maximum temperature:

   The monthly mean of the daily maximum temperature is often of concern for energy-related applications, including power generation and air conditioner unit sizing. It is also useful in ecological studies. Consequently, changes as the monthly mean temperature increases have the potential for direct impact-oriented scenario development.

4. Monthly mean of daily minimum temperature:

   This is the converse of the previous attribute, again providing information potentially useful for energy and ecological relationships.

5. Number of days per month with maximum temperature above selected threshold:

   The threshold is selected by the user. This is the attribute with the most clearly defined applications in, for example, agricultural and energy impact assessments.

6. Number of days per month with minimum temperature below selected threshold:

   This threshold is also user-selected. This is essentially the same attribute as number 5, and may have applicability in similar impact assessments.

Regression-Based Scenarios

The scenarios developed here use a combination of GCM results and observational data. Most of our knowledge about future climate comes form GCMs. These models, while the most sophisticated tools available, can give only general indications of average conditions over broad regions. Local, specific detail is often needed, however, if potential impacts of social and economic importance are to be assessed. This local information is derived from past observations of the climatic elements. The model and observational results are then combined to produce scenarios.

The regression approach was chosen as the scenario development technique because it came closest to meeting all the criteria for the project. The choice does not imply that the approach is always the most appropriate or scientifically sound. Certainly when the user's concern is with thresholds which are extreme values, techniques using extreme value or time series analyses are likely to be much more appropriate. Indeed, a strength of the present method is that when correctly used it precludes use of inappropriate results by indicating when the regression relationships are unsound.

Linear regressions are developed between monthly average temperature and each of the temperature attributes for each station, using the observational period of record or any portion thereof. These regressions are then used to determine changes in the attributes arising from changes in mean monthly temperature. Attribute changes are calculated for the mean monthly temperature changes postulated by the GCMs of (a) the Geophysical Fluid Dynamics Laboratory (GFDL), (b) Goddard Institute of Space Sciences (GISS), (c) the United Kingdom Meteorological Office (UKMO), and (d) Oregon State University.

Each GCM gives a different temperature projection so four different scenarios can be produced. There is no guarantee that these taken together provide the full range of possible futures, but they are likely to indicate the inherent uncertainty in the projections. Further, the temperature changes are those associated with a doubling of atmospheric CO_2, which is projected to occur sometime in the second quarter of the next century. This time scale depends on many nonclimatic factors, such as the level of global economic growth, or political actions to curb emission of greenhouse gases.

The effects of a wider range of possible future conditions, or assessment of the impacts in situations other than doubled CO_2, can be considered by using the option allowing the user to select any temperature change (cooling as well as warming). The program also calculates the effect of a 1° rise, testing the sensitivity of the attributes to changes in mean monthly temperature.

Program Overview

This section contains information about the operation of the program, and it includes some general considerations of program structure and organization to ensure that scenario development proceeds efficiently. The program is self-contained. However, (a) the daily temperature data needed for input are not included, and (b) the program does not produce presentation-quality graphics.

The large number of observing stations and the immense volume of temperature data potentially of interest for scenario development preclude the incorporation of the temperature data. Hence they must be obtained off-line and placed in the appropriate format for analysis. An increasingly common and convenient source of temperature data for analysis by PCs are optical disks. These are commercially available. Consequently, within the program are routines for using data downloaded from these optical disks, although explanations for using other data sources are also given.

Program outputs were designed to provide simple on-screen tables and graphics of the required scenario information. In addition, all outputs can be saved as ASCII files, so that more refined data analyses can be undertaken and higher quality presentations can be created.

Hardware Requirements

For program operation the following are required:

PC or Compatible
- 265 KB or more memory.
- A minimum of a 12-MHz 80286 machine with a math coprocessor is desirable, or file creation can be a long and slow process.

Hard Disk
- 500 KB free for program installation.
- Another 500 KB is recommended for data files storage, although less is actually required.

Monitor
- For display of on-screen graphics, a VGA card and color monitor are required.

Printer (optional)
- Dot matrix or laser

The program has been tested with a variety of hardware. However, there is no guarantee that it will work correctly with any specific combination of components.

Program Operation

The program is entirely menu driven. Once started, and the "Sign-On" screen has been cleared, the Main Menu is presented. This contains five options, the first three for scenario development, the final two for housekeeping. Scenario development proceeds sequentially through Main Menu options 1, 2, and 3. If optical disk data are used as the temperature input, development starts with option 1; if other sources are used, option 2 is the start.

Main Menu option 1 requests a choice of the temperature scale and the value of the high- and low-temperature thresholds to be used. The maximum and minimum temperature files created off-line from the optical disk data are then selected and used to produce the monthly and annual statistics.

The second Main Menu option is used to develop, from the monthly and annual statistics, the regression relationships between the various attributes and the monthly aver-

age temperature, and to examine these regressions. Choosing this options leads to a submenu. The first submenu option is for creation of the regression file, which must be the first action. The file thus created is then available for viewing, printing, or further analysis. This further analysis involves the creation of new files, either for an individual station throughout the year or for the whole area for a particular month. The results can be viewed or printed in tabular or graphic form. These files are designed to help investigate the confidence which can be placed in the regression approach.

Main Menu option 3 creates the actual scenario. Again there is a submenu, the first option of which is the creation of the scenario file. This uses the regression results and the temperature changes postulated by four GCMs to determine four scenarios for the selected attributes. In addition, results are calculated for a 1° temperature change (in the scale selected in option 1) and a change which is selected by the user. This scenario file is also available for further analysis, using new files created either for an individual station throughout the year or for the whole area for a particular month. Like the companion regression files, these are used to assess the confidence which can be placed in the results.

Option 4 allows the specification of the directories where the program and scenario development files are to be located, and it provides details of the hardware configuration. Finally, Main Menu option 5 contains various routines allowing the joining, deletion, or reformatting of the various scenario development files. These two options are housekeeping activities designed to allow efficient program operation while encouraging critical viewing of the scenario results.

The program has been formulated in such a way that, as far as possible, the user is forced to consider the validity of the results at all stages of the scenario development. This includes both the scientific validity of the whole approach in a particular situation and the statistical validity of the individual regressions. The program is designed to emphasize this continuous testing of results so that scientifically credible scenarios are developed. The practical expression of this formulation is that the program creates, and encourages inspection of, a series of files as the scenario development proceeds.

Scenario Development Example

The report uses the information contained in example files to develop a scenario. This is an example designed to show in more detail the method of program operation, indicate how a scenario might be developed, and suggest ways in which the confidence to be placed in the results can be assessed. The example chapter provides a detailed guide for using the program and includes many comments on the interpretation of results in order to create a valid scenario. It is assumed that the text and the example program will be used simultaneously.

Conclusions and Recommendations

A simple linear regression approach can be used for the development of scenarios of future temperature attributes. Using this approach, a scenario development software program, TEMPSCEN, for use on a personal computer, was created. This program can be used by knowledgeable persons concerned with the potential impact of climatic change in a specific region. The program is self-contained, the only data to be proved by the user being the daily temperature information for the places of interest. Throughout the scenario development, opportunities are provided for testing the validity of the results and assessing the degree of confidence which can be placed in them.

The temperature attributes used are monthly values of the standard deviation of daily temperatures, the diurnal temperature range, the mean maximum, the mean minimum and the number of days exceeding user-selected high- and low-temperature thresholds. These are regressed against monthly average temperature, using the historical observational climate record. Scenarios can be developed for any station having at least four years of daily maximum and minimum temperature data. Scenarios are developed for the temperature changes postulated by four general circulation models and for a temperature change selected by the user. Hence a suite of scenarios, indicating a variety of possible future conditions which are equally likely, is produced.

The program is menu-driven. Throughout the program frequent analysis of the output as development proceeds is encouraged. Context sensitive help is always available. This includes specific information about the steps in program operation and more general suggestions pertaining to the interpretation and analysis of scenarios.

The TEMPSCEN program allows simple, straightforward development of scenarios. It is recommended that the method be used when general estimates of future temperatures are needed.

There is no guarantee that future conditions will be anywhere near those projected using this method. Scenarios are limited to ranges of possible conditions. Results must not be used uncritically. The intermediate program products should be examined closely before any conclusions are drawn.

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Peter J. Robinson is with the University of North Carolina, Chapel Hill, NC 27599.
***Peter L. Finkelstein** is the EPA Project Officer (see below).*
The complete report, entitled "Temperature Scenario Development Using Regression Methods (Order No. PB91- 231 506/AS; Cost: $19.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
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U.S. Environmental Protection Agency
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