PAN-EARTH PROJECT

VENEZUELA CASE STUDY

PAN-EARTH/CEACT
International Workshop on
Climate Variability and Climate Change
in Venezuela and the Caribbean Region

Mérida, Venezuela
23-27 April 1990
Rigoberto Andressen  
University of the Andes and CEAFT  
"Evaluation of the GCMs for Venezuela,  
Determination of the Areas of Influence, and How to  
Create Scenarios"

Dr. Andressen presented a general diagram of the  
climate system. He discussed the fact that all the  
GCM grid boxes are too big, and that climatologists  
have to scale down to create realistic scenarios. A  
map of the climatic divisions of Venezuela was  
shown and compared to the grid box scale for  
Venezuela for each of the four GCMs discussed:  
GISS, UKMO, GFDL, and OSU. The Ackerman and  
Cropper (1988) methodology for interfacing GCMs  
and smaller models was discussed.

Dr. Andressen showed a rainfall map of Venezuela.  
In the south, there is high humidity, and the rainfall  
is more locally controlled than the Andean rainfall,  
where the orographic effect is greater. In the plains  
(Llanos), the rainfall is more homogeneous, with one  
rainfall peak and large spatial correlation.

Dr. Andressen took nine $10^9$ x $10^9$ grid boxes to derive  
precipitation data to compare to output from the  
GCMs (Figure 8). Seven were in the northern region  
and two in the south, to sample the different rainfall  
regimes in the country. For temperature, he used  
station data to represent each box, but for  
precipitation he used the rainfall atlas of Venezuela  
and station data to get an amount representative of the  
grid box average. He compared the actual data for  
temperature for four months and for precipitation for  
eight months against the output from each of the  
models. GISS and UKMO models gave the best  
results. But for these comparisons for both  
precipitation and temperature, the model results are  
practically the same for each station. All that  
changes on the diagrams are the data. The  
comparison with station data was done with GCM  
output from the maps, which interpolate between grid  
points.

The tables showing the models evaluated and the data  
comparisons are presented in the report of Working  
Group B, in a later section.

Ruben Aparicio  
Universidad de Oriente  
"Changes in Sea Level in the Caribbean"

In 1986, the UN asked for a report on the possible  
changes in sea level for the Caribbean, and scientists  
in the area began work under a NOAA program. The  
first task was to describe the climate of the region. A  
map of the Caribbean, $2.7 \times 10^6$ km$^2$, was prepared.

Changes to consider were: 1) increase of sea-surface  
temperature (SST) by 1.5°C; 2) increase of sea level  
by 20 cm; and 3) changes in large-scale variability of  
temperature, precipitation, evaporation, wind  
velocity, and storm frequency. Tide gauge data were  
used. The study looked at the implications for  
Venezuela and made recommendations. There were  
several objectives:

1) to examine the possible effects of changes of  
sea level on ecosystems;
2) to examine the possible effects of increased  
temperature on terrestrial ecosystems; and  
3) to examine the effects of physical changes in  
geography on ecosystems.

A map of the linear trend (mm\cdot yr$^{-1}$) of sea-level  
changes was prepared. Venezuelan coastal values are  
+2 and -2, after removing the atmospheric and long-  
term cyclical changes. The study will examine an 8-  
10 mm rise by the year 2025. At Maracaibo, the rate  
is 5.6 mm\cdot yr$^{-1}$. There are seven Venezuelan stations  
with records beginning from between 1953-1967 up  
to the present. Only three stations (Carupano, La  
Guaira, and Maracay) are operating now. Carupano,  
which shows a rising trend, only began in 1967;  
other stations also show a rising trend after 1967.  
The falling trend at other stations before 1987 makes  
understanding their longer-term trend difficult. From  
1982-86, the trends at La Guaira and Carupano are  
opposite, showing local seismic causes. These  
stations are along a plate boundary. The Caribbean  
plate is moving to the northeast, while the South  
American plate is moving toward the southwest.

The main impacts are:

1) submersion and loss of low-lying land;
2) saline intrusion into coastal aquifers, affecting  
local water quality and agriculture; and  
3) coastal erosion, with effects on tourism.

**ERRATUM SHEET:**  
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PAN-EARTH/CEACT
INTERNATIONAL WORKSHOP ON
CLIMATIC VARIABILITY AND CLIMATE CHANGE
IN VENEZUELA AND THE CARIBBEAN REGION

MÉRIDA, VENEZUELA
23-27 APRIL 1990

Organized by:

PAN-EARTH Project

and

Centre for Advanced Studies of the Tropical Climate (CEACT)
University of the Andes (ULA), Mérida

with support by:

University of the Andes (ULA), Mérida

Ministry of the Environment and Renewable Natural Resources
Division of Information, Research and Conservation of Water, Soil and Vegetation

and

Rockefeller Brothers Fund

THIS REPORT IS PRINTED ON RECYCLED PAPER
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Organizing Committee:
Miguel Acevedo (ULA, PAN-EARTH)
Rigoberto Andressen (ULA, CEACTION)
Claudio Caponi (MARNR)
Alicia Moreau (MARNR)
with
Alan Robock (University of Maryland)

AGENDA

Monday, 23 April 1990
10:00 a.m. - 6:00 p.m. Registration

7:30 p.m. Welcoming Remarks by:
Dr. Carlos G. Cárdenas (ULA)
Dr. Aníbal Rosales (MARNR)

Tuesday, 24 April 1990
8:00 a.m. PAN-EARTH Project: Venezuela Case Study, Mark Harwell (PAN-EARTH), Miguel Acevedo (ULA, PAN-EARTH)

8:45 a.m. Centre for Advanced Studies of Tropical Climate (CEACT), Alicia Moreau (MARNR)

9:30 a.m. Session 1: Paleoclimatic Information and Present Day Climatic Variabilities

Paleoclimatic Aspects of Venezuela; Carlos Schubert (IVIC)

10:30 a.m. Meteorological and Hydrological Data in Venezuela, Present Situation; Claudio Caponi (MARNR)

11:15 a.m. lunch Agroclimatological Survey of Venezuela; Edgar Ramirez (MARNR)

2:00 p.m. Rainfall Variability in the Venezuelan Llanos; Rigoberto Andressen (CEACT), Ramón Jaimez (PAN-EARTH)

2:45 p.m. Rainfall Regimes in Venezuela; R. Pulwarty (CIRES, University of Colorado, U.S.A)
3:45 p.m. New Aspects on Venezuelan Rainfall; H. Riehl (CEACT)
4:30 p.m. Panel Discussion on Climatic Variability

Wednesday, 25 April 1990
8:00 a.m. Session 2: General Circulation Models and Production of Climate Scenarios
OLR Data Regional Analysis: Physical and Computational Aspects; Luis Hidalgo (UCV)
8:45 a.m. Theoretical Aspects of GCMs; Alan Robock (University of Maryland, PAN-EARTH)
9:30 a.m. Preliminary Assessment of Some GCMs for Venezuela; R. Andressen (CEACT), R. Jaimez (PAN-EARTH)
10:30 a.m. GCMs: Scaling Methodology; A. Robock (University of Maryland, PAN-EARTH)
11:15 a.m. - lunch Organization of the Working Groups
Group A: Climate Variability
Group B: Climate Scenarios Generation
2:30 p.m.-5:30 p.m. Working Groups A and B Sessions

Thursday, 26 April 1990
8:00 a.m. Working Groups A and B Sessions
11:00 a.m. - lunch Panel Discussion of the Results of Working Groups A and B Reports
2:00 p.m. Session 3: Climatic Variability and Climate Change Impacts on Agriculture and Water Resources: Organization of Working Groups C and D
Group C: Ecology and Agriculture, Ecological and Crop-Weather Models, M. Acevedo and M. Harwell (PAN-EARTH)
Group D: Water Resources, Regional Hydrological Models, R. Duque (CIDIAT)
4:00 p.m. - 5:30 p.m. Working Groups C and D Sessions

Friday, 27 April 1990
8:00 a.m.- lunch Working Groups C and D Sessions
2:00 p.m. - 5:50 p.m. Panel Discussion on the Results of the Working Groups C and D Reports
5:30 p.m. Closing Session and Adjournment
OPENING SESSION

Dr. Miguel Acevedo presented the welcoming remarks for the morning session, followed by a brief overview of the PAN-EARTH Project presented by Dr. Mark Harwell. Dr. Acevedo continued the discussion with an informative overview of the Venezuela PAN-EARTH Case Study. The primary objective of the present workshop is to evaluate climate variability in Venezuela and to develop appropriate climate change scenarios for Venezuela as input to the PAN-EARTH effects assessments.

With core funding from the Rockefeller Brothers Fund, the PAN-EARTH Project coordinates the implementation of international research pertaining to global climate change and its effects on the environment. The Venezuela Case Study is one of several PAN-EARTH-sponsored research cooperatives. Initially funded by a small grant from the PAN-EARTH Project, the Venezuela Case Study now requires further funding to provide core support for ongoing case study activities including: workshops and training sessions, meetings, investigative projects, and general coordination of the case study. Funding for this workshop has been provided by MARNR, CONICIT, and ULA. The current workshop and case study participants include staff from such institutions as ULA, FONAIAP, Ministry of the Environment, IVIC, Venezuelan Air Force, ULORSTOM, and CEA, as well as scientists from the U.S. and the Caribbean. The Venezuela case study coordinators continue negotiations to strengthen their collaborative research network within Venezuela. As a result of this canvassing effort, IVIC has agreed to provide support for the July 1990 workshop on ecological effects, and discussions with Air Force officials are underway in pursuit of a joint research venture.

Venezuela PAN-EARTH Case Study priorities are:

- to establish accurate regional global climate change scenarios using expert judgment and based on General Circulation Model (GCM) outputs; to devise new methodologies for assessing historical climate data on a regional scale; to examine and refine issues of scale and spatial/temporal resolution;
- to assess effects on agricultural systems using the IBSNAT/DSSAT models as a base (a PAN-EARTH/FONAIAP workshop in November 1989 focused on calibration of the IBSNAT maize model and other models, for different areas of Venezuela);
- to assess climate change effects on ecosystems; to identify and adapt appropriate models to examine savannah and forest areas of Venezuela; to establish cooperation with IVIC and ULA for the July workshop; to identify other institutions involved in studying ecosystems, such as CIDIAT;
- to assess the areas of influence of meteorological stations in Venezuela to define which areas to study.

A number of PAN-EARTH workshops for the Venezuela Case Study have been or soon will be held:

May 89 - CONICIT sponsored a mini-workshop in Caracas to define and prioritize problems associated with the study of global climate change issues for Venezuela; ULA sponsored a mini-workshop in Mérida held at IFLA to identify areas of research.

November 89 - FONAIAP (Maracay) workshop focused on use, training, and calibration of IBSNAT/DSSAT models for assessing effects on maize and soybeans.

April 90 - CEA (Mérida) workshop addressed issues of variability of climate and the development of global climatic change scenarios for Venezuela.

July 90 - IVIC (Caracas) workshop will look at the methodologies of assessing ecological effects in Venezuela of global climate change.
PAPERS PRESENTED

Following the introductions and overview of the PAN-EARTH Project, the Venezuela Case Study, and the workshop organization and purpose, a number of papers and discussions of recent research were presented by workshop participants. A synopsis of each presented paper follows:

Alicia Moreau
Ministry of the Environment and Natural Resources (MARNR)
"Climate Change Activities at the Centre for Advanced Studies of the Tropical Climate"

Work on the hydrologic cycle is one focus of Ministry of the Environment and Natural Resources (MARNR) activities; these functions are performed through the meteorology and hydrology unit, directed by Dr. Moreau. This work was previously done in a different ministry and institute, but there has been recent emphasis in MARNR on these systems. Venezuela is rich in data but poor in information. The ministry is trying to use these data to make quantifications of Venezuela hydrological and meteorological conditions. In 1982, the Division of Meteorology was established and began studies. At present the division is working to develop catalogs of data and to develop geographical information systems.

Climate issues also require attention to hydrology and surface water systems. MARNR has created a group to study climate, and hydrological scientists have been added to this group. In 1969, a program of studies of meteorology was prepared for Venezuela. From these studies the Centre for Advanced Studies of the Tropical Climate (CEACT) at the University of the Andes was established. President Perez and MARNR Minister Colmenares participated in a recent international meeting on the global environment. Climate change studies are ideally located in Venezuela as it is in the tropical zone, there are diverse hydrological systems, and the Amazon region is relatively uninhabited. In addition, Venezuela contains one of world's major river systems.

MARNR brought CECT to the ULA in Mérida as a focus not just for Venezuela but for all countries in the region; therefore this has become an international center. The intent is to expand the knowledge base and number of members participating in research. Global climate change is an ideal focus for developing understanding of known and missing knowledge bases.

Alan Robock
Department of Meteorology
University of Maryland, U.S.A.
"Creating Regional Climate Change Scenarios"

Dr. Robock spoke of the record of global temperature changes in the past 100 years, for both the Northern and Southern Hemispheres. The global climate has warmed irregularly by about 0.5°C during the past century. Climate could change even more in the future from anthropogenic inputs to the atmosphere. At the present workshop, Venezuela-specific scenarios will be developed for three phenomena: nuclear winter, the increase in greenhouse gases, and deforestation. Dr. Robock showed slides depicting climate change predictions under different emission scenarios for carbon dioxide. For the tropics, changes in precipitation will likely be more important than temperature changes.

The primary objective of the PAN-EARTH case studies is to determine the ecological and agricultural effects of climate changes. These analyses are based on the specific climate change scenarios established for a specific region. Steps to create these scenarios are: 1) to examine historical and present climate variability in Venezuela for a number of specific locations representing a diversity of climatic zones; 2) to compare those data with outputs from a suite of general circulation models (GCMs) for the current climate; 3) depending on the accuracy of the GCM control simulations, to examine GCM outputs of altered atmosphere and to develop a range of scenarios of changes in average temperatures and precipitation; and 4) to recommend specific climate change scenarios to bound the sensitivity analyses performed for ecological and agricultural effects assessments. The first step looks at variability at present across space and time, including seasonality and interannual variability, to compare with the GCM output. Dr. Rigoberto Andressen performed a great deal of these analyses to prepare for this workshop. For creating climate change scenarios, the GCM output and local data have to be used together.

Dr. Robock prepared a paper for a PAN-EARTH workshop held in Senegal, Africa, in September 1989. The paper discusses the methodology used to create climatological scenarios for Africa, but the methodology is applicable to any regional area, and will be used for the Venezuela Case Study. The paper also discusses the uses and limitations of GCMs. That paper is reprinted in full in Appendix B.
Carlos Schubert  
Venezuelan Institute of Scientific Research (IVIC)  
"Aspects of Paleoclimate in Venezuela"  

Dr. Schubert presented research he has done on climatic changes in the last glacial maximum in Venezuela (see Appendix C for full paper). He showed a map of sea surface temperature deviations based on the paleological record and a map of the climate over the continents in the last glacial period. Dr. Schubert discussed the differences in albedo in the present as contrasted with during the last glacial maximum. Another map shown was by Hyman, on desert zone changes during the last glacial period. Other figures showed northern South America and the past distribution of biomes such as forests and savannas.

Examples of evidence of past climates in Venezuela were shown in the aerial photographs of dunes in the plains area. These dunes have been dated at about 13,000 years old, and may have been caused by a different climate. Another example is from Lake Valencia; sediment cores show drastic changes in the sediment, indicating coastal-like systems existed there in the past. Other lake sediments containing pollen from the past show there were different elevations than at present.

The presence of large river-transported boulders in areas without rivers suggests different hydrologic regimes existed in past climate conditions. Analog for future climate change can be created by comparing past and present climate regimes and vegetation in different regions of Venezuela.

Claudio Caponi  
Ministry of the Environment and Natural Resources (MARNR)  
"Diagnostics of Actual Meteorological Data and Hydrological Data for Venezuela"  

One of the tasks of the PAN-EARTH case study in Venezuela is to identify data bases for climate systems. Present climate and hydrological data exist in Dr. Caponi's unit at MARNR. His group also looks at conservation of soil and geologic data. Maps showing meteorological and hydrological stations in Venezuela were displayed (Figures 1 and 2).

In 1965, MARNR started recording consistent information at all stations. By 1982 there was too much information, so MARNR created a data bank on a mini-computer. There is too much data to handle on a daily basis, so a monthly data base was established; there are about 11 disks of information available now. MARNR obtained a hydrological and meteorological data base management system from Belgium, and in 1987 converted to this system with data management on a regional basis. Dr. Caponi overviewed the state of the data by type, frequency of collection, and incorporation into the computer data base, and showed a chart of the number of stations with monthly or daily data and a plot of the number of years of meteorological and hydrological data available for all 20 Venezuelan states (Figures 3 and 4). The unit at MARNR is now receiving satellite images on a 3-hr basis and saving these on microfilm.

Dr. Caponi gave a brief overview of the Air Force weather system. He then discussed a project to digitize maps of different regions, with interpretation of satellite images and other maps.

Edgar Ramirez  
Ministry of the Environment and Natural Resources (MARNR)  
"Overview of Agroclimatology in Venezuela"  

Dr. Ramirez presented information about agroclimatology in Venezuela. His research is primarily focused on agricultural productivity, to evaluate climate in order to improve productivity and reduce costs and risks. The purpose of this work is to look in real time at the climate in relation to effects on agriculture. This work involves:

1) characterizing agroclimatic zones, i.e., identifying areas with agricultural potential based on monthly climatic data;

2) evaluating the operation of agricultural systems and their implementation;

3) performing agroclimatic-specific investigations to work on problems and derive benefits from resources; and

4) disseminating agrometeorological information

To illustrate the classification of agroclimatic zones, some research results for the state of Anzoategui were presented. This included a map of the agroclimatic
<table>
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<th>Parameters</th>
<th>Operating Stations</th>
<th>Data Published daily</th>
<th>Data Published monthly</th>
<th>Data Digitized daily</th>
<th>Data Digitized monthly</th>
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<td>67 --&gt; 81</td>
<td>67 --&gt;89</td>
<td>inst.--89</td>
<td>inst.-- 67</td>
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<td>67 --&gt;74</td>
<td>--</td>
<td>*87 --&gt; 89</td>
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<td>86 --&gt; 89</td>
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<td>per.variab.</td>
<td>67 --&gt; 89</td>
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<td>inst.--77</td>
<td></td>
<td>67 --&gt; 89</td>
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</table>

*Tank "A"-Evaporation instrument

inst.-installed

C1-First order climatological station (precip., temp., evap., rel. humidity, solar radiat., wind speed and direction)

C2-Second order climatological station (precip., temp., evaporation)

FIGURE 3
### DATA ON A MONTHLY BASIS

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<tr>
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<td>Solar Radiation</td>
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<td>Cloudiness</td>
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<td>300</td>
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<tr>
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</tbody>
</table>

**FIGURE 4**
zones, a map of the main river, and a watershed map. Areas were identified for planting sorghum, and times to plant sorghum were specified. This region is one of the last areas in Venezuela to begin the rainy season. These maps play an important role in the determination of meteorological influence areas.

Dr. Ramirez discussed procedures for the zonification of crops. These procedures include:

1) study evapotranspiration (ETP) by comparing stational radiative indices;
2) determine growing periods;
3) determine cumulative moisture evaporation (CME) of water in soil; and
4) determine agricultural and ecological requirements.

The duration of the growing season was identified for each area of the region; longer- and shorter-maturing crops were identified by area. The research includes an analysis of the risk from drought impacts on crops. With increased growing season length, there is an increased risk of drought impacts. A map showed the areas where there is a risk of semi-drought, comparing precipitation with ETP and 1/2 ETP each year. This must be considered in identifying the appropriate planting date. Dr. Ramirez showed a chart of the probability distribution functions of risk of impacts from drought. There is a higher risk in the northern part of the region.

This kind of analysis is being done for all of Venezuela. For the first phase, all climatological data are available. From these data, researchers analyze what shifts in agricultural practices are appropriate.

Eli Henry
Meteorological Service, Trinidad and Tobago
"Climate Variability in Trinidad and Tobago"

Trinidad and Tobago is a nation just northeast of Venezuela. Dr. Henry's presentation focused on what is being done to cope with climatic change. Concern has been expressed with regards to impacts on Trinidad and Tobago from:

1) changes in the frequency of natural events such as floods and storms;
2) the fact that the 1980s have been the warmest decade in this century;
3) the depletion of the ozone layer; and
4) prospects for sea-level rise.

The regional situation in the Caribbean is that their contribution to global pollution is almost negligible; trade winds export all pollutants from the Caribbean region, but they bring pollution in from African and European sources. The primary concern is the possibility of the increase in hurricane intensity and the movement of storm paths southward, as seen in Hurricanes Gilbert (1988) and Hugo (1989). The role of air/ocean coupling is extremely important. A NOAA project on air/ocean fluxes in the region is presently looking at annual and interannual signals for possible relevance to climate change issues. A working group studying sea-level rise is collecting data in a hydrographic unit; these data will be available in a year or two.

An environmental information system is being developed in Trinidad and Tobago to collect all information on the environment. There is a task force looking at atmospheric pollutants (vehicular and from quarries and industry) to quantify pollution sources prior to reductions in emissions. They are also working to develop programs for replanting coral reefs, reforestation, and the protection of mangroves, plus reduction of CO2 emissions.

The meteorological office is concerned about Saharan dust arriving during the dry season. Dust inputs may be increasing because of the spread of the Sahel, or the trends could result from better monitoring and increased awareness. In 1988 Trinidad and Tobago had their first tornado (100m wide and a 1/2 mile path). Questions are being asked if this was associated with a general warming in 1980s. Also there has been increased riverine flood frequency in the 1980s, especially in 1981, 1985, and 1988. There is concern about the extremely dry dry-seasons in 1987 and 1988, which put pressure on water resources. Is this from climatic variability or from climate change? The record is too short to make this judgment.

Dr. Henry showed a plot of the mean annual temperature for Trinidad and Tobago for 1946-89, showing a definite warming trend from 25.1°C to 26.7°C in 1987, but the record is too short to know if this is a long-term trend. A plot of the mean annual precipitation shows a continual increase from 1790mm to 1870mm in the last 30 years (1960-89).
These data were from an airport station. Another station shows a more sinusoidal pattern over the same period; thus it is not clear what the trend is for the country as a whole.

The primary wet period is from May-August; September-December is the secondary wet period. The first wet period has remained about the same over time, but the secondary wet period has shown a major increase in precipitation. This has implications for water management. The Trinidad and Tobago Meteorological Service has installed the CLICOM system (same as in Venezuela), and is soon to have eight automatic weather stations; all data will go to regional units as well as to scientists.

The full text of Dr. Henry's paper is presented in Appendix D.

Roger Pulwarty
University of Colorado
"Precipitation and Atmospheric Circulation Patterns for Venezuela"

Dr. Pulwarty reported on a harmonic analysis of precipitation in Venezuela, deriving maps from the National Meteorological Center (NMC) of relative vorticity patterns. As the intertropical convergence zone (ITCZ) moves northward during the end of the year, it pushes out the relative vorticity patterns. He compared a station precipitation anomaly index with a 15-year mean and calculated the relative difference. A map showed the distribution of anomalies with a sum of all the stations with a greater than or less than 20% deviation from normal. A table showed the interannual variability of precipitation over Venezuela from 1972-1986; this gives a picture of the general situation over Venezuela for the time period.

Dr. Pulwarty found the correlation of the southern oscillation to be <0.2, so this effect is not very important in determining actual precipitation patterns. For average wet and dry years, he found some regions differ from the average response. His research confirms the extreme complexity of precipitation in Venezuela, and the question arises of how to model something so complex, including the Atlantic, Caribbean, ITCZ, and cross-equatorial influences.

Dr. Pulwarty showed maps of the Outgoing Longwave Radiation (OLR) for each month. The region of minimum OLR, indicating high cold clouds that are usually associated with precipitating thunderstorms, moves from the Amazon region in January to Panama in June, staying there through September, then beginning to move south in October. In November, there is no area of deep convection, but it reforms in the Amazon in December. But it is known that there is rain over Colombia in November, so OLR is not giving the whole picture. More land-based data are needed to study this because the upper air data from models and OLR are both poor measures of the precipitation pattern. A recommendation was made by Dr. Pulwarty to establish a working radiosonde station in Venezuela.

Luis Hidalgo
University of Central Venezuela (UCV)
"Analysis of Outgoing Longwave Radiation (OLR) Data"

Dr. Hidalgo presented results of research done in collaboration with Nobre, Miller, and Kousky, published in NOAA CAC Bulletin and in an article in Rev. Physics 563(3), 1985 (also see NOAA Atlas No. 6 [OLR Data], Peixoto and Oort [1985], and Tropical-Ocean Atmosphere Newsletter, University of Miami).

Dr. Hidalgo described the NOAA satellites that were used to generate the data. The process of outgoing longwave radiation (OLR) from the cloud tops is that the colder the cloud tops, the lower the OLR. Cloud top temperature corresponds to altitude: the higher the cloud top, the colder the temperature. Since there is more precipitation the higher the cloud top, this is an imperfect measure of tropical precipitation.

Dr. Hidalgo examined anomalies of OLR, using digital data from a resolution of 2.5 x 2.5 degrees and a weekly average. There are 27 grid boxes that cover some part of Venezuela, but only four of these are completely inside Venezuela. The most important part is the watershed of Lake Maracaibo and the Orinoco. Analysis of data from 100°W-50°W and 25°N-25°S, for June 1974-August 1989, showed no long-term trend in the seasonal cycle averaged over the entire period of data for any of five regions. In Tablazo, in the region of Lake Maracaibo, the OLR minimum showed a distinct bimodal pattern, with a minimum at May and in September-October, the two periods of rainfall, based on actual data, not anomalies. They also tried to correlate these data with the air/ocean coupling El Niño-Southern Oscillation (ENSO) index, but ENSO is too distant and there was not a good correlation. The best data correlation was with precipitation, ±0.94.
Herbert Riehl
Centre for Advanced Studies of the Tropical Climate (CEAC.T), University of the Andes
"New Studies of Precipitation in Venezuela"

The relationships between land and water with respect to the equator are reversed from everywhere else in the world where there is a monsoon, so the character of the seasonal cycle is very confused. Storms at higher latitudes over both South and North America have trailing cold fronts, which sometimes affect Venezuela and provide a pump to produce deep convective systems in the absence of a monsoon.

Dr. Riehl showed a figure of relative vorticity for July 1976, with a grid box over Venezuela. There was an anticyclone with upward motion. In this case, the rainfall index of Pulwarty showed a rainfall maximum. But this is not always the case because of incursions of fronts from higher latitudes, which would not show up on a monthly average. One example from 13-18 September 1981, including satellite images, showed a system coming from the south, then curving to the east after it crossed the equator, as opposed to the usual westward-moving disturbances in the ITCZ. There are other types of impulses from the south also.

The monthly data show no relationship between the subtropical jet stream and Venezuelan rainfall, though daily data may show it. Upper anticyclones, related to the Amazon anticyclone in the Northern Hemisphere summer months, may come in bursts of energy from the Amazon and cause rainfall events. But in the middle of the rainy season, one often finds bursts of rainfall in Venezuela unrelated to external influences, especially in the east, for which there are no upper air data. In Mérida, most of such events are accompanied by rising pressure, associated with westward moving disturbances in the ITCZ, similar to thunderstorms in the mid-latitudes. The difference here is the large amplitude of the systems (~3 mb/24 hours).

In the east there is one rainfall peak in July, which has the same characteristics throughout the Caribbean. The most interesting aspect is what happens in the Andes. Studies during 1981-1989 of precipitation in Mérida looked at precipitation related to storms. In Mérida, there is a double peak in precipitation, with the maximum in May (230 mm) and October (250 mm), and a local minimum in July (100 mm). The Mérida data correspond well with the Pico Espejo (at the top of Teleferico) and San Antonio data (San Antonio is at sea level near Lake Maracaibo) (Figure 5). So the Mérida data seem to be representative of a larger region, at least on synoptic or climatic scales.

OLR data for a box over most of Venezuela correspond to precipitation data. This cannot be associated with the double passage of the sun, as is the traditional explanation. At the rainfall maximum, since it is cloudy, a large portion of the solar radiation is reflected, so it cannot be the driving mechanism through surface heating. In addition, this double minimum in OLR extends to north of 20°N, which is too far from the overhead sun.

There is also a double peak in humidity during this same period, using 500mb dewpoint depression data (temperature minus dewpoint temperature). This means that there is a deep moist layer in the lower atmosphere. Dr. Riehl showed a diagram of a large cloud on the eastern side of Andes, with a foehn wind on the west side drying the atmosphere as it sinks (Figure 6). In the easterlies, this is a traditional explanation for the change in rainfall across the ridge of the mountains. During the relatively dry period of June-August, the wind direction was more frequently from the west, showing that an inverse foehn effect reduced the precipitation in Mérida. The number of days with dewpoint depression ≥10°C corresponded well with the number of days with westerly winds (Figure 7). The precipitation deviation during June, July, and August correlated well with the number of days with dewpoint depression ≥10°C.

A conclusion is that this shows a mechanism that must be included in GCMs. This is a much more complicated situation than the Indian monsoon, to which so much attention has been paid. Dr. Riehl and his collaborators have made preliminary suggestions of the mechanisms for a pump which is unrelated to the double crossing of the ITCZ that can produce rainfall. It may be related to the summer heating in the southern United States, affecting the subtropical high. This occurs at longitude 80°W, exactly the longitude where the summer-time minimum occurs in Venezuela.
FIGURE 6
400 mb \( T - T_d \geq 10^\circ C \)

DIRECCION DEL VIENTO
EN 400 mb

FIGURE 7
Rigoberto Andressen  
University of the Andes and CEAoT  
"Evaluation of the GCMs for Venezuela, Determination of the Areas of Influence, and How to Create Scenarios"

Dr. Andressen presented a general diagram of the climate system. He discussed the fact that all the GCM grid boxes are too big, and that climatologists have to scale down to create realistic scenarios. A map of the climatic divisions of Venezuela was shown and compared to the grid box scale for Venezuela for each of the four GCMs discussed: GISS, UKMO, GFDL, and OSU. The Ackerman and Cropper (1988) methodology for interfacing GCMs and smaller models was discussed.

Dr. Andressen showed a rainfall map of Venezuela. In the south, there is high humidity, and the rainfall is more locally controlled than the Andean rainfall, where the orographic effect is greater. In the plains (Llanos), the rainfall is more homogeneous, with one rainfall peak and large spatial correlation.

Dr. Andressen took nine $1^0 \times 1^0$ grid boxes to derive precipitation data to compare to output from the Ruben Aparicio  
Universidad de Oriente  
"Changes in Sea Level in the Caribbean"

In 1986, the UN asked for a report on the possible changes in sea level for the Caribbean, and scientists in the area began work under a NOAA program. The first task was to describe the climate of the region. A map of the Caribbean, $2.7 \times 10^9$ km$^2$, was prepared.

Changes to consider were: 1) increase of sea-surface temperature (SST) by 1.5°C; 2) increase of sea level by 20 cm; and 3) changes in large-scale variability of temperature, precipitation, evaporation, wind velocity, and storm frequency. Tide gauge data were used. The study looked at the implications for Venezuela and made recommendations.

There were several objectives:

1) to examine the possible effects of changes of sea level on ecosystems;  
2) to examine the possible effects of increased temperature on terrestrial ecosystems; and  
3) to examine the effects of physical changes in geography on ecosystems.

GCMs (Figure 8). Seven were in the northern region and two in the south, to sample the different rainfall regimes in the country. For temperature, he used station data to represent each box, but for precipitation he used the rainfall atlas of Venezuela and station data to get an amount representative of the grid box average. He compared the actual data for temperature for four months and for precipitation for eight months against the output from each of the models. GISS and UKMO models gave the best results. But for these comparisons for both precipitation and temperature, the model results are practically the same for each station. All that changes on the diagrams are the data. The comparison with station data was done with GCM output from the maps, which interpolate between grid points.

The tables showing the models evaluated and the data comparisons are presented in the report of Working Group B, in a later section.

A map of the linear trend (mm•yr$^{-1}$) of sea-level changes was prepared. Venezuelan coastal values are +2 and -2, after removing the atmospheric and long-term cyclical changes. The study will examine an 8-10 mm rise by the year 2025. At Maracaibo, the rate is 5.6 mm•yr$^{-1}$. There are seven Venezuelan stations with records beginning from between 1953-1967 up to the present. Only three stations (Carupano, La Guaira, and Maracaibo) are operating now. Carupano, which shows a rising trend, only began in 1967; other stations also show a rising trend after 1967. The falling trend at other stations before 1987 makes understanding their longer-term trend difficult. From 1982-86, the trends at La Guaira and Carupano are opposite, showing local seismic causes. These stations are along a plate boundary. The Caribbean plate is moving to the northeast, while the South American plate is moving toward the southwest.

The main impacts are:

1) submersion and loss of low-lying land;  
2) saline intrusion into coastal aquifers, affecting local water quality and agriculture; and  
3) coastal erosion, with effects on tourism.
The main short-term potential effects for the coast involve tourism, oil and gas transport, and other commercial activities.

Indirect effects from climate change involve:
1) displacement of traditional fishing sites, impacting the local fishing industry. Dr. Aparicio showed maps of the present distribution of tuna, limited by temperature and the oxygen content of water. Tuna is an important part of fishing industry now.
2) changes in location of the Atlantic ocean area favorable for genesis of hurricanes and tropical storms. Dr. Aparicio showed maps of the important hurricanes in the Caribbean. In 1974, Hurricane Alma hit Trinidad and Venezuela, but hurricanes are rare at such low latitudes. There was also one in 1933 that just skirted the coast. During this century, there were four more hurricane paths that came about 300km from the coast.
3) enhanced evaporation in shallow coastal waters, because of higher temperatures; this can make the water more saline.

Mark A. Harwell
Cornell University
"Agricultural Effects Modeling: Using IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) Models for PAN-EARTH Assessments"

Dr. Harwell presented background material on the agricultural models that are used by the PAN-EARTH Project to assess effects of global climate change on agriculture within a region. IBSNAT is a project currently implemented by the University of Hawaii under support from the U.S. Agency for International Development.

The purpose of the IBSNAT Project is to develop a methodology for the transfer of agroproduction technology that combines elements of transfer by analogy with systems analysis and simulations. By combining soil, crop, weather, and farm management data bases with simulation models and expert systems, IBSNAT is developing a decision-support system that allows government agencies to undertake long-term, strategic planning and allows farmers to make day-to-day tactical decisions. This systems-based approach (Figure 9) emphasizes interdisciplinary teamwork, since understanding gained from the physical, biological, social, and economic disciplines is needed for efficient and effective agrotechnology transfer.

The objectives of the IBSNAT Project are to:
1) accelerate the flow of agrotechnology from its site or origin to new locations;
2) maximize the successes and minimize the risk associated with the transfer of agricultural technology; and
3) assess the long-term effects of agricultural practices on the agroecosystem.

IBSNAT aims to achieve these objectives by:
- establishing a global prototype network to generate information necessary to develop and test a decision-support system for agrotechnology transfer;
- demonstrating the usefulness and applicability of the systems-based approach in developing countries;
- training scientists in developing countries to utilize this methodology; and
- catalyzing the establishment of regional networks that employ systems-based methods for the transfer of agrotechnology.

The IBSNAT project has developed the Decision-Support System for Agrotechnology Transfer (DSSAT), which is essentially a shell for data entry, simulation specification, model execution, and representation of model outputs. DSSAT is implemented on PC-compatible (DOS) microcomputers. DSSAT consists of a database management system that facilitates entry of data on soils, cultivar characteristics, farming practices, and climate. A suite of crop simulation models are included, at present for wheat, soybean, maize, peanut, dry bean, and other important food crops. Each simulation model is designed to be generic, i.e., to be adaptable, with input of appropriate data on soils, climate, and cultivars, to virtually any region where the crop may be grown. The models have been shown to simulate both crop productivity and crop phenology accurately. The user-interface components of DSSAT allow specification of a range of scenarios, altering the initial conditions and weather for each simulation. Output capabilities include built-in graphics as well as data-file creation for subsequent statistical or graphical analyses.

The PAN-EARTH Project has selected the DSSAT package for assessing agricultural sensitivities to climate change because of the diversity of crop models included, their adaptability to the variety of regions under study by PAN-EARTH, the relative ease of implementing the models and training the
Figure 9. The decision support system integrates soil data, experimental data, crop data, weather data, and existing knowledge about the farming systems to enable collaborators to make decisions about production outcomes.
scientists in their use in the case study countries, and the relatively minimal data needed for simulations. The approach of PAN-EARTH is to calibrate models to specific sites and crop cultivars in the country (e.g., maize model calibration for Venezuela was accomplished at the PAN-EARTH Maracay workshop [November 1989]), to simulate crop production using actual weather records for selected years at the selected crop sites, and to simulate crop production under identical conditions, except that the daily weather is modified to reflect region-specific climate change scenarios.

One advantage of the rapidity of simulation of these crop models is the capability to conduct a very large number of sensitivity analyses. As an example, if the PAN-EARTH climate scenarios are for, say, an increase in average precipitation by 25%, that could be imposed by altering the amount of rainfall per event, the number of rainfall events, the onset of the rainy season, the end of the rainy season, etc. How this is done could have a significant effect on the predicted impacts on crop production. PAN-EARTH will exploit the sensitivity analysis approach to characterize the nature of climate change-crop effects relationships. Such simulations are presently underway for Venezuela maize, and the climate change scenarios of the present workshop will provide critical guidance to this activity.

Roberto Duque
Interamerican Center for the Integral Development of Water and Land (CIDIAT)
"Hydrology Models"

There are a wide variety of hydrology models that can be used to evaluate changes in hydrology. The four steps that will be taken are:

1) identify the spatial scale to be simulated, such as a reservoir;
2) choose the time resolution: a small time-step allows a more complex formulation while a large-time step allows a faster run, but may miss some processes;
3) construct the mathematical formulation; and
4) test the model; actual precipitation inputs are used to compare predicted vs. actual runoff.

The application uses a parametric approach for the design, operation, and management of hydrological systems, such as dams, urban infrastructure, or irrigation. Design can determine the capacity of a reservoir, or the size of an urban storm drain. Operations can tell when to open a dam.

Management can determine the land use in a watershed, or how many years to have an aquifer reach a certain level.

For the purposes of this workshop, an important question is how much water will be available in a watershed. The model needs precipitation and evaporation data as input. This does not include the biological control of evaporation. On a daily scale, the model can simulate soil moisture and subsoil processes, but on a monthly scale it can only simulate evaporation from the upper soil layer. Precipitation is the main input that drives the entire system. The model uses a set of storage compartments such as aquifers, reservoirs, soil, lakes, and rivers, and simulates the transfers between the various compartments; this is basically an accounting procedure.

For the monthly level model, there are only three compartments: surface, soil, and underground. The input is rain, rivers, and subsoil flows. The output is runoff and underground flow. To calibrate the model, precipitation, evaporation, and runoff data are needed. There are not enough data in Venezuela to calibrate an evaporation model to calculate evaporation as a function of temperature. There are many regions where this model may not be calibrated, such as the River Chama, which has a lot of subterranean flow. Hydrodynamic process models are available, all descendents of the Stanford model, but they require too much computer time and require separate calibration for each watershed.

Dr. Duque showed the details of the model components: it calculates evapotranspiration using basically the "bucket" method. He described an infiltration model, from soil surface down into soil. The precipitation that does not infiltrate goes into runoff. Percolation is a function of infiltration and soil moisture. Percolation is from the soil to the aquifer, and is lost for the possibility of re-evaporation. Soil moisture is a balance between precipitation, evapotranspiration, and percolation. Aquifer input is a balance between percolation, subterranean input, and subterranean output. The imbalance is the storage, and is calculated as a residual.

Dr. Duque showed the application of the model for the Rio Doradas Basin (564 km²). The model does not capture the peaks and minima during the four-year period shown. This may be because of the unrepresentativeness of the input data, which come from only a few precipitation stations in the basin.
They used only four years of data and calibrated and validated with the same data. Longer-term data sets do not exist because of the relocation of rain gauges in the watersheds.

Following the presentations of papers, the workshop participants dividing into four working groups. The reports of the working groups follow.

WORKING GROUP REPORTS

WORKING GROUP A
CURRENT VARIABILITY OF PRECIPITATION, TEMPERATURE, AND INSOLATION

The working group’s first approach was to determine the method to use, considering the short time available. Two methodologies were used:

1) Discriminating wet versus dry years using monthly data for precipitation in Venezuela. The group had tables of the stations, with data available for 1966, ’81, ’82, and ’87, for temperature, precipitation, and radiation. It was decided to look at the months of January and July as representative, and not to do all months. January is a dry month and July is a wet month.

2) Examine extreme monthly values to establish a working hypothesis. The 1976-81 and 1982-87 periods were examined at for comparison. A caveat: it is hard in the short term to reach solid conclusions. Thus this is a preliminary hypothesis with a reasonable basis. The group took the average of all stations and found in some cases that there was variability, but in other cases the variation was small. Results allow the group to consider several hypotheses: the dry period tends to be less dry and the wet period less wet; the variability of air temperature is very small, except stations near water bodies. The working group recommends to revise the definition of variability, repeat this study with a more complete data base in a systematic fashion to see if one can use stations with estimated data or only those with complete data sets, and to do a correlation with stations with similar climate, e.g., map vegetation, soils, and physiography across a landscape.

Conclusions:
1) dry periods are getting wetter;
2) wet periods are getting drier;
3) temperature variation is small except near water bodies.

WORKING GROUP B
DEVELOPMENT OF CLIMATE CHANGE SCENARIOS

Leader: Alan Robock (Univ. of Maryland)
Rapporteurs: Alan Robock [in English] Rigoberto Andressen (ULA-CEACT) [in Spanish]
Participants: Aparicio, Ruben (UDO)
Azocar, Aura (ULA)
Colloti, Eva (UCV)
Henry, Eli (Trinidad and Tobago)
Maytin, Carlos (ULA)
Noguera, Cesar (MARNR)
Perdomo, Martha (MARNR)
Petit, Jesus (CEACT)
Pulwarty, Roger (Cires)
Quintero, Carlos (LUZ)
Ramirez, Edgar (MARNR)
Riehl, Herbert (ULA)
Rincon, Benedicto (CEACT)
Schubert, Carlos (IVIC)
Tonella, Giorgio (ULA)
Zambrano, Zosimo (CVG)

Working Group B will provide scenarios for use in the crop models for four different types of future climate change:

1) nuclear winter;
2) Amazon deforestation;
3) 2 x CO₂;
4) combination of 2 x CO₂ and Amazon deforestation.

For each of these types of climate changes, it is necessary to go through several steps to create the scenarios, following the methodology of Ackerman and Cropper (1988). These steps consist of answering these questions:

1) How well do the GCMs simulate the current climate? Do some models do better? Which ones?
2) What are the patterns of climate change forecast by the models? Do the different models agree?
3) Based on 1 and 2 (above), can we create a model-based scenario? Which model should we use? Or should we average the results?
4) Can we use current interannual variability to create scenarios? What is the specific character of these variations? For precipitation, for example, when there is a wet year, which is the most important factor: timing of the rainy season, spacing of rainfall events, intensity of rainfall events, or extremes?

5) How specifically should we modify the current climate? For example, for a month that is 3°C warmer, do we add 3°C to the maximum and minimum temperature for each day of a current time series; do we add 9°C to 1/3 of the days and 0 to the rest; do we add 4°C to the minimum and 2°C to the maximum, or some other combination? For precipitation, which of the characteristics in 4 (above) do we modify?

6) Finally, what are the scenarios? Is there a preferred order, if they all cannot be run?

NUCLEAR WINTER

We only have the output from one GCM, the Lawrence Livermore National Laboratory calculation done by Steve Ghan using a version of the OSU model. We only have the results for two grid points, at 60°N, 65°W and 10°N, 65°W, which are labeled Venezuela. We can also refer to the recent summary of expected nuclear winter climatic effects by Turco et al. (1990) and to the comments by Ghan provided with the graphical results.

If the Ghan calculation is similar to the OSU 1 x CO2 results that we do have, it does a very good job of calculating the Venezuelan temperature, but a poor job on the precipitation. This need not be a serious obstacle, since the climate changes calculated by the model for nuclear winter are very large, much larger than the errors of the model for temperature. However, since the model does not do a good job in all the parameters, we must still question whether it gets the temperature correctly just by chance, since it must have errors in the basic physics or resolution. However, since the changes are so large, and agree with results from other models not available here, we will use these results as a basis for a scenario. For precipitation, the results are quite noisy, and therefore we will produce several precipitation scenarios that are based on the general expectations for this type of climate forcing, as described in the above references. The specific scenarios will not depend strongly on this particular GCM simulation.

There were three runs performed, all beginning on 1 July, with 15, 50, and 150 teragrams (TG) of smoke for 30-day runs of the model, and two runs, for 50 and 150 TG of smoke, for 12-month runs. In addition there was a control run for the current climate. The results are shown in the accompanying tables. Other simulations, such as those by Robock (1984) and those reported in Turco et al. (1990), show that for smoke injection in the Northern Hemisphere in winter, the surface temperature effects are less and the transport from mid-latitudes to the tropics is less. Nevertheless, we recommend that the nuclear winter scenarios presented below be started at each month to do a worst-case analysis for crop effects. The 50 TG case for winter will be a more likely worst case for smoke injection in the winter months, but it is possible that, depending on the particular targeting scenario chosen, the effects could be greater.

In the short term, only the 150 TG case shows significant temperature changes, with the maximum and minimum temperature going down by 5-10°C for the period 5-15 days after the detonations. For days 20-30, the temperatures are 2-3°C above the control. In the longer term, both the 50 and 150 TG cases show significant temperature drops, but the maximum drops are in the months October-June, the dry season. During the rainy season, there is much more cloudiness (water clouds), and the smoke does not reduce the insolation as much, but in the dry season, the smoke alone can cause greater insolation reductions, resulting in greater temperature decreases. This agrees with the insolation results, discussed in the next paragraph. At 10°N the cooling for October-December is larger than at 60°N, but after that the results agree. The main differences for these two grid points are in the control simulations, not in the nuclear winter ones. At 10°N in the control, there is more insolation during this period (presumably because of lower cloudiness) and therefore higher temperatures. For the 150 TG case the dry season temperature drops average 8-10°C for maximum temperature and only 2-4°C for minimum temperature, in agreement with our understanding of the effects of smoke on radiation. Since the smoke particles are sub-micron size, they strongly absorb shortwave radiation (of similar wavelength to the particle size), but do not interact strongly with the longwave radiation, resulting in less effect at night. For the 50 TG case, the drops are about the same as the 150 TG drops in October, but decrease to about half of the 150 TG drops by January.

Insolation is greatly reduced in the 150 TG case for days 5-20, and somewhat for the 50 TG case. For both the 15 and 50 TG cases, there were days with greatly enhanced insolation, perhaps because of
removal of the clouds that were there in the control. For the longer term, there are immediate reductions of 50-70% for the 150 TG case that last until February, after which they gradually go down to close to normal by June. For the 50 TG case, the reduction gradually increases to 40% in November, after which it goes down to less than 10% by March.

The precipitation changes are not nearly so clear. For the 50 TG case there are small reductions and enhancements in the rainy season, and after October, very small changes. For 150 TG, July precipitation is virtually zero, after which the changes resemble the 50 TG case. For this scenario, we will have to use the advice of Ghan and Turco et al. and refer to larger-scale averages and results.

DEFORESTATION

We have only one model run available, that by Shukla et al. (1990). The control case is not available for Venezuela; only regionally averaged control values are given, and maps of the differences. However, this model does a good job with the current climate in South America, since it includes the SiB biosphere model of Sellers et al. (1986), and is very high resolution, with about 18 vertical levels and horizontal grid spacing of less than 2 degrees.

The attached tables show the details of the results. For Venezuela, we find temperature increases of 0.5-1.5°C and precipitation decreases of 300-600 mm/year. The temperature increases are similar for all months of the year, and the precipitation decreases are about 20-30% for the entire year.

2 x CO₂

Rigoberto Andressen has analyzed the OSU, GISS, GFDL, and UKMO GCMs and compared the simulations of the current (1 x CO₂) climate with data from nine stations from different rainfall regimes for precipitation and temperature, and for six larger regions of Venezuela for precipitation. See the following tables for the details. In general, the UKMO model reproduces the present climate reasonably accurately, but the others do not.

The report by Andressen contains tables that show the UKMO model simulations for Venezuela for 2 x CO₂. The UKMO model shows a larger temperature increase in the dry season (January), equal to about 5°C for all the Venezuela stations, and about 3.5°C for the rainy season (July). This makes sense, since it is clear during the dry season, and the downward longwave will be more effective at heating.

For precipitation, the model shows no change during the dry season and enhanced precipitation by about 25% during the rainy season up to July, with a reduction by 10% in August and little change in September and October. Since this does not seem consistent with our understanding of the synoptic-scale dynamics of the rainy season, the working group looked at the precipitation simulations of the other three models. All show enhanced precipitation during the rainy season, but not as much as the UKMO model. OSU showed more of an increase in August than in July, with a 50% increase, and the other models showed less of a change, but not a reduction.

There was no insolation information from the models available at the workshop, so we will have to use expert judgment, including our understanding of the relationship of tropical cloudiness to precipitation. Monthly average insolation information from three of the models at grid points is available from the EPA diskettes produced at NCAR. A review of these monthly average results shows that for the Venezuela region, the GFDL model gives decreases of insolation by as much as 15% when precipitation increases. The UKMO model also has decreases of insolation by as much as 10% for large precipitation increases, but has insolation increases for smaller precipitation increases or precipitation decreases. The GISS model has virtually constant insolation, no matter what the precipitation changes. Wetherald and Manabe (1986) claim that all the models they reviewed show decreases in insolation when the surface gets warmer.

Models that produce more convective clouds in response to heating can produce more precipitation and less insolation in a warmer climate. This aspect of climate models, generation of fractional cloudiness, is one of their poorest components, as demonstrated by wide variety of results above. The experience of Venezuelan climatologists, especially Riehl, is therefore a very important source of information for the insolation portion of the scenario. They find that it is cloudier during rainy periods, even if the clouds do not produce rain. That is, insolation goes down when rainfall goes up. This, therefore, will be the primary scenario, and the model results will be used for secondary scenarios.

We will base the scenarios on the UKMO results, with additional general guidance from the other models. Since the UKMO is the most sensitive of all the GCMs to 2 x CO₂, with a 5.2°C global average temperature increase, we will consider its results as the upper range of the scenarios.
NATURE OF CURRENT INTERANNUAL VARIABILITY

According to Riehl, who has conducted extensive analysis of the character of Venezuelan rainfall over the past several decades, we must modify the precipitation by changing the number of events, not by changing each event by a constant amount. At present most of Venezuela, only 10 hours per month of heavy rain produces about 85% of the total rain for the month. This is only 1.4% of the total time of the month. Thus, we can modify the precipitation by changing this to 1.2% or 1.0% for decreasing rainfall, or increase it for increasing rainfall.

Strong hurricanes have affected Venezuela twice during the past century. Although rare now, they can have devastating consequences. Although the GCMs do not explicitly simulate hurricanes, the GCM results for 2 x CO₂ were analyzed by Pulwarty and Riehl for the conditions necessary for hurricanes. All the models suggested that sea-surface temperatures in the region to the northeast of Venezuela would increase by several degrees. This implies that hurricanes crossing this region would be more intense than now, and that there would be more hurricanes than at present. For this reason we include a hurricane as one possible 2 x CO₂ scenario.

METHOD FOR CREATING SCENARIOS FROM CURRENT CLIMATE

Since the responses to nuclear winter and 2 x CO₂ are quite different in the rainy and dry seasons, and since the rainy season and dry season have different timings in different parts of Venezuela, we will divide the scenarios into those for the dry season and those for the wet season at each station. Dry months are defined as those with less than 50 mm of rain during the month, based on the analysis of Venezuelan rainfall by Andressen and Riehl.

The relative direction of changes of each parameter are different for each of the three types of climate change, because of the different physics of each forcing:

<table>
<thead>
<tr>
<th>TEMPERATURE</th>
<th>PRECIP</th>
<th>INSOLATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>max</td>
<td>min</td>
<td></td>
</tr>
<tr>
<td>NUCLEAR WINTER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 x CO₂</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>DEFORESTATION</td>
<td>+</td>
<td>—</td>
</tr>
</tbody>
</table>

TEMPERATURE: The temperature in Venezuela stays relatively constant throughout the year. The diurnal cycle is less during the rainy, cloudy season, but the daily mean does not change very much. Within a month, there are not large daily changes of temperature, as fronts rarely affect the temperature this close to the equator. Therefore, we will modify time series of current data by the same amount for each day of a month, keeping the day-to-day variance the same. This is true for all three types of scenarios.

For nuclear winter, the maximum temperature will be reduced more than the minimum temperature, because of the radiative physics of smoke particles, as discussed above. For 2 x CO₂ for large increases of temperature, we will change the minimum temperature more than the maximum temperature, based on the physics of longwave radiation. The enhanced downward radiation will be more effective at night, when there is no competition with sunlight. This is especially significant during the dry months. For deforestation, the changes will be small, and there is no good reason for distinguishing between minimum and maximum.

PRECIPITATION: When increasing rainfall, we will do it by increasing the number of rainfall events, not the intensity of each event. This is because, as discussed above, a small number of intense events account for most of Venezuelan rainfall. The procedure is as follows:

1) Find the largest rainfall event in the month.
2) At random, pick another day in the month with no rainfall and change that day to the amount equal to the largest day.
3) Continue this procedure until the total monthly rainfall is equal to the prescribed change.
4) Use a fraction of the amount of the largest day for the last day added in order to make the total correct.
5) If there are no days left in the month with no rainfall, continue with the day that has the least rainfall, and increase it until it is equal to the largest day.
6) When reducing rainfall, remove days with rainfall starting with the largest.
7) Remove a fraction of the last day, if necessary to make the total correct.

INSOLATION: For nuclear winter, the insolation changes will be associated almost exclusively with the smoke in the atmosphere, which will be modified by the cloudiness. The insolation changes will thus be applied to each day of the month. For 2 X CO₂, change the insolation for the days with changed rainfall by an amount equal to the percent change for
monthly rainfall. For the days of the month for which rainfall is not changed, change the insolation by half of the above amount. This is to account for the fact that in a more rainy climate, even those days for which precipitation does not change, the cloudiness will change. Two secondary insolation scenarios are for insolation not to change as precipitation changes and for insolation to go up as precipitation goes up by half the amount of the precipitation changes for the days on which precipitation is changed, and by one fourth that amount on the other days of the month. For deforestation, the insolation will go up because of less cloudiness, but cannot go larger than what it would be for clear-sky conditions. Therefore, it will be increased by a fixed percentage for each day, with an upper limit.

\[
\text{Nuclear winter: For any arbitrary starting date, apply the following two scenarios:}
\]

<table>
<thead>
<tr>
<th>Smoke Injection:</th>
<th>Season</th>
<th>Temperature</th>
<th>Precipitation</th>
<th>Insolation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Daily Max.</td>
<td>Daily Min.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-50°C</td>
<td>-30°C</td>
<td>-25%</td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>-30°C</td>
<td>-20°C</td>
<td>-25%</td>
</tr>
<tr>
<td></td>
<td>Wet</td>
<td>-10°C</td>
<td>-5°C</td>
<td>-50%</td>
</tr>
<tr>
<td></td>
<td>Wet</td>
<td>-5°C</td>
<td>-3°C</td>
<td>-50%</td>
</tr>
</tbody>
</table>

\[
\text{Deforestation: Change maximum and minimum temperature by +1°C for all months. Reduce precipitation by 25% for all months. Increase insolation by 25% for all months, subject to the limitation of maximum clear sky insolation.}
\]

\[
\text{2 x CO}_2:\text{ There are three 2 x CO}_2\text{ scenarios, High, Middle, and Low, corresponding to different levels of sensitivity of the climate system (i.e., different levels of temperature change per unit increase in radiatively important gases). Each scenario is equally probable. The temperature and precipitation scenarios should be run at the same corresponding levels. Insolation is to be changed as discussed above.}
\]

<table>
<thead>
<tr>
<th>Season</th>
<th>Temperature</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Daily Max.</td>
<td>Daily Min.</td>
</tr>
<tr>
<td>High</td>
<td>+4.0°C</td>
<td>+6.0°C</td>
</tr>
<tr>
<td>Dry</td>
<td>+3.5°C</td>
<td>+3.5°C</td>
</tr>
<tr>
<td>Wet</td>
<td>+3.0°C</td>
<td>+4.0°C</td>
</tr>
<tr>
<td>Wet</td>
<td>+2.5°C</td>
<td>+2.5°C</td>
</tr>
<tr>
<td>Middle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>+2.0°C</td>
<td>+2.0°C</td>
</tr>
<tr>
<td>Dry</td>
<td>+2.0°C</td>
<td>+2.0°C</td>
</tr>
<tr>
<td>Wet</td>
<td>+2.0°C</td>
<td>+2.0°C</td>
</tr>
</tbody>
</table>

An alternative way to change the precipitation is to change each day by the same percentage. In this case, the insolation for each day will be changed by half of the amount (in percent) that the precipitation is changed. We recommend that this be a secondary method, but should be included since, even though it is not synoptically sound, it is the method used by other groups. This will serve as a sensitivity test to see in which cases the method of changing the precipitation makes a difference.

\[
\text{Hurricanes: In a warmer world, the probability of hurricanes will increase. To simulate this, add one day in September or October with rainfall of 50 cm.}
\]

\[
\text{Deforestation and 2 x CO}_2:\text{ Add 1°C to each of the temperatures and 25% to each of the precipitation values for the 2 x CO}_2\text{ scenarios.}
\]

\[1\text{Dry months are those with less than 50 mm of rain.}\]
### TABLE 1

Preliminary Evaluation Of Most Accurate GCMs for Precipitation

<table>
<thead>
<tr>
<th>Geographic Area</th>
<th>Quantity</th>
<th>Rainy Season Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maracaibo</td>
<td>OSU</td>
<td>GFDL</td>
</tr>
<tr>
<td>Paraguana</td>
<td>GISS</td>
<td>GFDL</td>
</tr>
<tr>
<td>Caracas</td>
<td>GFDL</td>
<td>OSU</td>
</tr>
<tr>
<td>Barinas</td>
<td>UKMO</td>
<td>UKMO</td>
</tr>
<tr>
<td>Acarigua</td>
<td>UKMO</td>
<td>UKMO?</td>
</tr>
<tr>
<td>Guaro</td>
<td>UKMO</td>
<td>OSU</td>
</tr>
<tr>
<td>Maturin</td>
<td>GFDL</td>
<td>UKMO?</td>
</tr>
<tr>
<td>Puerto Ayacucho</td>
<td>UKMO</td>
<td>UKMO?</td>
</tr>
<tr>
<td>Sta Elena</td>
<td>UKMO</td>
<td>UKMO?</td>
</tr>
</tbody>
</table>

**UKMO-based Precipitation Changes**
(ratio of precipitation for \(2 \times \text{CO}_2 / 1 \times \text{CO}_2\))

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maracaibo</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.14</td>
<td>1.4</td>
<td>0.8</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td>Paraguana</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.3</td>
<td>1.5</td>
<td>0.75</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td>Caracas</td>
<td>1.0</td>
<td>1.3</td>
<td>1.0</td>
<td>1.35</td>
<td>1.3</td>
<td>0.8</td>
<td>1.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Barinas</td>
<td>1.0</td>
<td>1.1</td>
<td>1.0</td>
<td>1.14</td>
<td>1.3</td>
<td>0.9</td>
<td>0.9</td>
<td>1.1</td>
</tr>
<tr>
<td>Acarigua</td>
<td>0.9</td>
<td>1.1</td>
<td>1.0</td>
<td>1.2</td>
<td>1.3</td>
<td>0.9</td>
<td>1.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Guaro</td>
<td>0.8</td>
<td>1.3</td>
<td>1.1</td>
<td>1.2</td>
<td>1.2</td>
<td>0.9</td>
<td>0.9</td>
<td>1.1</td>
</tr>
<tr>
<td>Maturin</td>
<td>0.9</td>
<td>1.5</td>
<td>1.25</td>
<td>1.5</td>
<td>1.2</td>
<td>0.9</td>
<td>0.9</td>
<td>1.2</td>
</tr>
<tr>
<td>Puerto Ayacucho</td>
<td>1.0</td>
<td>1.2</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>0.8</td>
<td>0.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Sta Elena</td>
<td>0.9</td>
<td>1.2</td>
<td>1.1</td>
<td>1.0</td>
<td>0.9</td>
<td>0.85</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Trinidad</td>
<td>0.9</td>
<td>1.6</td>
<td>1.75</td>
<td>1.75</td>
<td>1.2</td>
<td>0.8</td>
<td>1.0</td>
<td>1.2</td>
</tr>
</tbody>
</table>

### TABLE 2

Preliminary Evaluation Of Most Accurate GCMs for Temperature

<table>
<thead>
<tr>
<th>Geographical Area</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maracaibo</td>
<td>GISS</td>
</tr>
<tr>
<td>Paraguana</td>
<td>GISS</td>
</tr>
<tr>
<td>Caracas</td>
<td>GISS</td>
</tr>
<tr>
<td>Barinas</td>
<td>UKMO</td>
</tr>
<tr>
<td>Acarigua</td>
<td>UKMO</td>
</tr>
<tr>
<td>Guaro</td>
<td>UKMO/GISS</td>
</tr>
<tr>
<td>Maturin</td>
<td>GISS</td>
</tr>
<tr>
<td>Puerto Ayacucho</td>
<td>GISS</td>
</tr>
<tr>
<td>Sta Elena</td>
<td>UKMO</td>
</tr>
</tbody>
</table>

**UKMO-based Temperature Changes from Greenhouse Scenarios**
(°C difference between \(2 \times \text{CO}_2\) and control simulations)

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Apr</th>
<th>Jul</th>
<th>Oct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maracaibo</td>
<td>4.3</td>
<td>2.7</td>
<td>3.5</td>
<td>3.6</td>
</tr>
<tr>
<td>Paraguana</td>
<td>3.7</td>
<td>3.2</td>
<td>3.3</td>
<td>3.5</td>
</tr>
<tr>
<td>Caracas</td>
<td>4.7</td>
<td>4.0</td>
<td>3.1</td>
<td>3.7</td>
</tr>
<tr>
<td>Barinas</td>
<td>5.5</td>
<td>2.0</td>
<td>3.6</td>
<td>4.0</td>
</tr>
<tr>
<td>Acarigua</td>
<td>5.0</td>
<td>2.8</td>
<td>3.5</td>
<td>3.8</td>
</tr>
<tr>
<td>Guaro</td>
<td>6.0</td>
<td>4.0</td>
<td>3.4</td>
<td>4.2</td>
</tr>
<tr>
<td>Maturin</td>
<td>5.0</td>
<td>4.5</td>
<td>3.0</td>
<td>3.8</td>
</tr>
<tr>
<td>Puerto Ayacucho</td>
<td>6.4</td>
<td>3.0</td>
<td>3.6</td>
<td>4.4</td>
</tr>
<tr>
<td>Sta Elena</td>
<td>6.4</td>
<td>4.0</td>
<td>3.3</td>
<td>4.4</td>
</tr>
<tr>
<td>Trinidad</td>
<td>3.5</td>
<td>4.0</td>
<td>2.9</td>
<td>3.5</td>
</tr>
</tbody>
</table>
WORKING GROUP C
AGRICULTURAL MODELS

Working Group Leader:
Maria Martelo (MARNR)

This working group took the calibrated maize model as used at the Maracay workshop (April 1990) for cultivar 66, used the soil and weather data for the Turen site, and took 1983 as the base year. Then the group went through the process of altering the model input to fit the first scenario of Working Group B: a high sensitivity temperature change plus a change in precipitation and insolation. This involved using the Cropper WEATHER program to modify the real actual year's data. The model crashed as there were -99 values in the middle of the growing season, so the group had to modify the base weather data by inserting days with the same information as a nearby day with or without precipitation. This required cycling through the program to make changes in different parts of the year. Then the group had to change the WTH.DIR file so DSSAT could locate the weather data. Then the group ran the model.

The group changed the weather file input, the soil to type 42 (typical of the Turen area as stated in the Maracay workshop report), and the cultivar to be 66. This process was done for the base case, scenario 1 (as above), scenario 2 (temperature change only), and scenario 3 (temperature and insolation change only). It was found that the base yield was about 15,000 kg·ha⁻¹, and the scenario 1 yield was about 9000 kg·ha⁻¹ (a 30% reduction). When the model was run with a temperature increase and no change in precipitation or insolation, yields were about 11000 kg·ha⁻¹. Thus, the working group ran it again with only temperature and insolation to see why the difference in results. The group found the same yield with both precipitation increase and insolation decrease. Thus they found that precipitation changes made no difference (1983 was a wet year and this was good soil, so at no time did the crop experience drought stress), but there was an effect from reducing insolation by 20% during the wet season. This was all the group had time to do at this workshop as DSSAT is difficult to modify for climate changes and the EPA version with temperature and precipitation sensitivity analyses built in crashes on the maize model. There are three years of weather data for Turen, and some group members will later do the model runs for all three, as they did for the base year.

Additionally, more data will be obtained from FONAIAP and MARNR, and these data will allow more runs to see if the results are sensitive to interannual variability. Later, a set of sensitivity analyses will be performed beyond the specific scenarios set by Working Group B, to examine the effects of different types of changes.

WORKING GROUP D
HYDROLOGY

Working Group Leader:
Jorge Rodriguez (UCV)

The working group selected the SIHIMTA model with a monthly time scale. They analyzed six precipitation scenarios: low, medium, high, maximum extreme, minimum extreme, and average of maximum and minimum. The low scenario had a factor of 1, the medium 1.2, and the high 1.4.

The time series used was of the Guanapito station for 1966-1987. Other scenarios used were catastrophe scenarios.

The group generated runoff for all the scenarios, then selected the Neveri River watershed, 900km². The group worked with physiographic data for the watershed and climatic data from the Guanapito station.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>538</td>
<td>0%</td>
</tr>
<tr>
<td>Medium</td>
<td>693</td>
<td>+29%</td>
</tr>
<tr>
<td>High</td>
<td>851</td>
<td>+59%</td>
</tr>
<tr>
<td>Extreme maximum</td>
<td>1542</td>
<td>+187%</td>
</tr>
<tr>
<td>Extreme minimum</td>
<td>125</td>
<td>-77%</td>
</tr>
<tr>
<td>Average max-min</td>
<td>713</td>
<td>+33%</td>
</tr>
</tbody>
</table>

Under the medium scenario, results were similar to the average of maximum and minimum scenario, but this may be a coincidence. A relationship may be derived between the amount in the scenario and the amount in runoff as delta values.
FINAL SESSION

Following the presentation of the working group reports, Dr. Rigoberto Andressen led a general discussion and the closing ceremony.

Dr. Carlos Schubert (IVIC) presented recommendations to the general plenary session on incorporating paleoclimatic research into the PAN-EARTH Project activities in the Venezuela Case Study. Those recommendations are:

- Monitoring of glaciers in Venezuela and Colombia (collect these data every six months or every year at least)
  - photographic records
  - geodetic records
- Detailed study of Holocene stratigraphic sequences.
  -- continental sequences; peat deposits in the Andes and Guayana Shield (mainly palynological and radiocarbon analyses), climatic changes (mainly temperature and moisture)
  -- marine terraces along the northern coast of South America and offshore islands—sea level change
  -- marine peat deposits (mainly mangroves)—sea-level changes

Further discussion by the participants included proposals for future workshops in Venezuela and the Caribbean to examine other issues associated with climate change effects and to help the region prepare for future problems. Workshop members discussed the difficulties in using current climate change information for the tropics, in obtaining adequate data bases, and in developing models for tropical systems. Plans for publication in the open literature of articles on the PAN-EARTH methodology and preliminary results were discussed.

The meeting adjourned after appreciation was expressed to all the sponsors, organizers, and participants.

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APPENDIX A

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APPENDIX B
GCM Greenhouse Warming Scenarios for Africa

(Paper presented at PAN-EARTH Workshop on Effects of Climate Change
with Emphasis on Sub-Saharan Africa, Saly, Senegal, September 11-15, 1989)

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ABSTRACT

Global climate may change rapidly in the next century, and it is important to begin now to develop techniques to assess the impacts of this change on human activities. There are many problems associated with this endeavor, including defining the required climate information, and primitive, imperfect understanding of the course of future climate. Results of calculations of the effects of increasing greenhouse gases from general circulation models of the earth's atmosphere are presented. Suggestions are made as to how to produce scenarios for use in impact analysis in Africa, with an emphasis on multi-disciplinary teams.

1. Introduction

Many scientific studies warn of a rapid global climate change during the next century as a result of increased greenhouse gases in the atmosphere (National Research Council [NRC], 1979, 1983, 1987; World Meteorological Organization, 1986a, 1986b; the "State-of-the-Art" reports of the Department of Energy [MacCracken and Luther, 1985a, 1985b; NRC, 1985; Trabalka, 1985; Strain and Cure, 1985; White, 1985]; Ramanathan, 1988). They all suggest that the effects of greenhouse warming will become dominant over the natural variability of climate, including the effects of volcanic eruptions, ENSOs, internal circulation variations, and possible solar variations, and agree that surface air temperatures will rise, precipitation patterns will change and sea level will rise.

Even though these projections of the future are crude, it is important to begin now the assessment of the human impacts of these potential climate changes on a global basis, as has been done already for the United States (Smith and Tirpak, 1989). Because of the time lags inherent in the climate system, current actions will determine the future climate and hence, the human impacts. The results of current impact analysis, even if imperfect, will be useful in the design of future climate models to produce not just parameters of interest to atmospheric scientists, but parameters that will be needed by society, and in the design of technological responses to ameliorate the human impacts.

Although climate models simulate the entire globe and have fairly coarse resolution (typical grid spacing of 500 X 500 km), impacts are felt on local scales. This coarse resolution not only limits the ability of the models to produce valid simulations on a global scale, but it also makes it difficult to derive parameters on scales smaller than that of the models. And in order to study these impacts, scenarios which can be applied to many different activities and systems are needed. In this paper, the currently available climate model calculations for Africa are described. Samples of output from these calculations are presented in maps. These results will be useful as input for the generation of scenarios for case studies of the impact of climate change in Africa.

2. Defining the Required Information

In order to produce a scenario of future climate for use in impact analysis, it is first necessary to know the particular activity that will be impacted, and its sensitivity to different climate parameters. Only then can useful scenarios be provided that include information on the important parameters with the appropriate temporal and spatial resolution.

Scenarios will be needed to study the impacts on a large number of systems that affect humans, including agriculture, forests, transportation, water resources, wetlands, human health, rivers, lakes, estuaries, biodiversity, coastal resources, air pollution, electricity demand, and societal and political systems. For each of these, the most important climate parameters in a world with a different climate may not well known. For instance, ocean currents, frequency and strength of oceanic storms, winds, frequency of fog, sea ice distribution and thickness, and sea level as it affects navigation in shallow straights and harbors will all...
be important for ocean transportation, while temperature, precipitation, cloudiness, CO₂ concentration, intensity of ultraviolet light, frequency of hail, and soil moisture will all be important for agriculture, although of different relative importance for different crops in different areas of the world at different times of the year. In addition, the frequency of rare, but extreme, events, such as hurricanes, drought, flooding, tornadoes, hailstorms, heat waves, and frost, may be more important than shifts in the mean of standard variables. And for each of the important parameters, the appropriate spatial and temporal distribution of the parameter must be provided. For example, the ocean currents may only be needed on a monthly basis in 1000 X 1000km boxes, while temperature might be needed every hour at a specific location on a hillside near a coastline where a rice crop is being grown.

For many of the impacts, especially in agriculture, which is probably the most important one, since it directly affects the global food supply, the sensitivities are not well understood. Research is just beginning into the effects of changing different parameters and their distributions, either singly or in combination, on agricultural production. Therefore, it is very difficult at this time to specify the needed parameters, or their time or space resolution. Crop models are in their infancy, especially if they are expected to be applied in climatic regimes beyond our experience where nonlinear threshold effects may be important. And models of intermediate resolution, including fields or landscapes do not properly consider the very small scale or very large scale factors that may be important.

In all the above discussion another factor, technological change, has not been considered. The predominant factor in changes in virtually all the activities listed above in the past century has been technological improvements, not climate. It is not known how to predict future technological change and its interaction with climate. Furthermore, technological reaction to perceived climatic change, such as developing drought resistant seeds, or redirecting military resources to reforestation, may completely dominate future impacts. Societal reactions, such as mass migrations or revolutions, may also be more important than the direct effects of changing climate parameters on specific activities.

There are several possible methods to assess the impact of climate change, including actual field experiments under controlled conditions, simulation models, statistical models, studies of distributions of vegetation in current and past climates, and historical records of responses to weather and climate extremes. For each of these techniques, different types and resolutions of climatic information may be necessary in the scenarios.

In lieu of the results of research to answer all the questions addressed above, it is still possible to begin to address the sensitivities of small parts of this complex system in order to identify areas where research should be directed. Before it is possible to create detailed scenarios, it will be necessary to specify the priorities of impacts that will be addressed, and to find out from experts in these fields their best current judgment of the important parameters that will be needed, with the needed temporal and spatial resolution and the most useful form of the information, such as statistical distributions or frequency of extreme events above or below certain thresholds.

3. Creating Climate Change Scenarios
Given that we can accomplish the steps discussed above, and that we have a long list of climate parameters that need to be specified in scenarios of the future, how can these scenarios be produced? One possibility is to use information from the recent instrumental record. Another potential technique is to use paleoclimatic information. The obvious tools to use are general circulation models (GCMs) of the earth's atmosphere, but they also have many problems. Arbitrary scenarios, of changing parameters by specified fixed amounts, is another possibility.

Information from the Instrumental Record. Smith (1989) used the warm decade of 1930-1939 as an analog for a warmer future world. This method has three problems. First of all, the parameter used to choose this decade was global average surface air temperature, and many important climate parameters may have not been at their extreme values then. Secondly, it is now as warm as that decade in many parts of the world, and we would like to create scenarios of a climate quite different from the present one. And third, the 1930s probably were warm due to lack of volcanic aerosols for the preceding 2 decades, and it is now warm probably due to the compensating effects of cooling by volcanic aerosols, warming by more greenhouse gases, and the largest El Niño of the century (Robock, 1989). Superimposed on both of these time periods is the natural variability of climate, which was different in the different periods. So that using a different
period with the same mean climate, but due to different causes, may produce an entirely different distribution of climate parameters and not be a good analog.

Paleoclimatic Information. The same problem as discussed above also applies to using paleoclimatic information. As shown by MacCracken et al. (1989), warm periods in the past were caused by different forcings than potential greenhouse-gas-induced warming and had different seasonal and latitudinal distributions of solar energy. Therefore they may be quite inappropriate to use for scenarios of the next century. One would expect quite different distributions of atmospheric circulation, precipitation, monsoons, and seasonal cycles produced by greenhouse gases as compared to Milankovitch forcing.

Scenarios From Climate Models. GCMs of the earth's atmosphere have been used by 5 different groups (Oregon State University - OSU, National Center for Atmospheric Research - NCAR, Goddard Institute for Space Studies - GISS, Geophysical Fluid Dynamics Laboratory - GFDL, and the United Kingdom Meteorological Office - UKMO) to calculate how the global climate will change in response to doubling the CO₂ concentration in the earth's atmosphere. These are called equilibrium calculations. The UKMO, OSU, GFDL, and GISS results are currently available at NCAR for analysis and use in generation of scenarios. Groups in the USSR, Australia, West Germany, and Canada are also doing equilibrium calculations. In addition, the GISS, GFDL, and NCAR models have been coupled to ocean models and used to calculate the time-dependent transient response of the climate system to gradual increase of greenhouse gases. The GISS transient calculations, made with a simplified, non-dynamic ocean model, are also currently available at NCAR. The GFDL and NCAR transient calculations were made with full oceanic GCMs, and therefore allow more possible modes of response.

The latest calculations that are generally available at NCAR are described in three appendices which are available by request to the Global Environment Program at Cornell University. Appendix A, by Dennis Joseph, lists the information currently available on tape, including the parameters available from each model. Appendix B, by Roy Jenne, discusses in some detail the characteristics of the climate models used for these calculations. In Appendix C, sample maps from the currently available calculations are presented for Africa for the current climate and for the altered climate.

More calculations are always being done, and will become available in the future. For instance, GFDL has completed two more calculations that should be available within the next year: a higher resolution R30.2 X CO₂ equilibrium calculation and the transient calculation with a full oceanic GCM.

Although these calculations have a coarse resolution and disagree on regional distributions of climate change, they can be used for creating ranges of scenarios for studying the impact of climate change. In order to create scenarios for individual locations, at least five related approaches have been recently suggested. Wigley et al. (1988) evaluated multiple linear regression techniques for calculating sub-grid-scale information. Turco (1988) suggested a method for using the seasonal cycle to scale the local changes from GCM output. Ackerman and Cropper (1988) described a scheme to combine GCM output, local climatology, and expert judgment to create scenarios. Karl et al. (1989) developed a statistical technique employing empirical orthogonal functions to obtain local information. Smith (1989) has actually used simple procedures to create scenarios for United States impact studies, including 2 X CO₂ GCM runs, and transient GCM runs.

Although GCMs give the best current picture of the climate of the future, and can be used to produce physically consistent scenarios, they still have large deficiencies in their ability to predict the future.

In the first place, it cannot be assumed that the climate will gradually warm, as is the implicit assumption in using a 2 X CO₂ equilibrium simulation, or a smoothed transient simulation with only greenhouse gases for forcing and a simple mixed layer ocean, as in the GISS transient run. Even though the global climate has warmed during the past century (Jones et al., 1988), this warming may be entirely due to natural variations in the climate system, and totally unrelated to greenhouse gases (Robock, 1978; Lorenz, 1989). The amount of future climate change that will occur due to internal variation in the climate system is not now well known (Lorenz, 1989). Volcanic eruptions may play an important role in the future climate, depending on the frequency and amplitude of future eruptions (Robock, 1989). Although Hansen et al. (1988) include volcanic eruptions in some of their transient scenarios, these are just guesses as to the
future level of volcanic activity. Cooling cannot be excluded from climate change scenarios for the next few decades, and must be considered in any set of scenarios.

In the second place, GCMs do not properly consider many important physical and biological processes. Clouds, soil hydrology, and ocean circulation, and the biological impact on the first two of these, are the major deficiencies that we can identify today. For example, when the UKMO included more realistic, but not necessarily more correct, cloud microphysical calculations in their 2 X CO$_2$ experiments, the global sensitivity went from a 5.2°C warming to only 1.9°C warming (Mitchell, 1989). (It is the calculation with the 5.2°C sensitivity that is currently available for analysis.) When Manabe et al. (1989) at GFDL coupled an oceanic GCM to their atmospheric GCM in a transient experiment, they actually found cooling in the Southern Hemisphere (SH) as the Northern Hemisphere warmed. Even after a 200 year integration during which the atmospheric CO$_2$ concentration increased by a factor of 4, the air temperatures in the high latitudes of the SH failed to warm! Even if the system was warming everywhere, different parts of the climate system warm at different rates. Therefore, gradients will be set up and produce anomalous responses that cannot be seen in the equilibrium calculations. No greenhouse warming calculations have yet included a biosphere model, yet recent calculations of Amazon deforestation (Nobre, personal communication) with the National Meteorological Center GCM coupled with the SIB biosphere model (Sellers et al., 1986) showed large effects of the biosphere on soil moisture and cloudiness. And this is with a very crude, GCM-grid-size biosphere model. How can GCM output be used to evaluate the effects of climate change on agriculture or forests, when the simulation did not include this biology in its calculations?

GCMs cannot even do a good job of reproducing the current climate (Grotch, 1988) due to the above problems and the resolution of the models. If they do not even include the necessary physics to satisfactorily simulate the current climate, how can we believe their simulations of altered climate?

The variability of climate may also change as the mean changes. Rind (1989) shows that in his simulations, as the climate warms the temperature variability decreases while the hydrological variability increases. Can the GCM model results be used to produce this aspect of the scenarios? Variability of the current climate is already very large, especially of the hydrological cycle, and we already know that extreme events, such as the 1988 midwestern U.S. drought, hurricane Gilbert in 1988, or the Sahel drought, can have devastating effects on humans. Will the future climate actually be more variable than this?

Another aspect of climate variability is the scale of temporal and spatial variation. Do the models produce the correct variability for the current climate? How can sub-grid-scale variation be addressed? Will future climates be distinguishable from the present large variability on the local scale?

There are also advantages to using GCMs. They produce information for the entire world, and produce sets of parameters that are physically consistent, within the physics of the model. For instance, they do not produce increased precipitation and decreased cloudiness at the same time (unless, of course, the distribution of convective to layer cloudiness changed drastically). GCMs also produce results for specified causes of climate change, and different experiments can be set up to answer different research questions.

**Arbitrary Scenarios.** Guided by the results of the GCMs and the needs for the study of a particular impact, a climatologist could arbitrarily specify combinations of parameters that would be self-consistent and span the range of possible future climates. This could be the same for many different impacts, in order for all to study the same scenario, or could be tailored to a specific impact, so that the sensitivities could be optimally determined.

4. **Suggested Steps To Create Scenarios**

In light of all the problems listed above, how can we create scenarios for the PAN-EARTH case studies? I think that it is obvious that although a long-term research program is necessary to produce credible scenarios of the actual future climate, we can begin now to develop the experience necessary for this work. This research must include specialists from a number of different disciplines working together, and we have the opportunity here to proceed with case studies.

In the short term, I do not think it is useful to apply sophisticated statistical techniques to current GCM output. I think the only practical method to produce useful scenarios on a short-term basis is to use multi-disciplinary teams to carry out the following steps:
• Identify specific activities for case studies of climate impact;
• Identify locations for the case studies;
• Identify the methods to be used for the impact analysis;
• Specify the climate parameters with their required spatial and temporal resolution that will be needed; and
• Use expert judgment of climatologists utilizing the outputs of GCMs and their knowledge of the climate and microclimate of the regions of the studies to produce a set of arbitrary, reasonable, simple scenarios of the required parameters, along the lines of the method suggested by Ackerman and Cropper (1988).

In this way, scenarios will be created that include all the required parameters with the required resolution. Since the object of our preliminary work is identification of sensitivities, not the prediction of the entire impact on humans of climate changes, the GCM results to date will be useful as guidance, but need not be perfect.

A long-term research program of improvement of GCMs as well as techniques of impact analysis will be the only way to definitively answer the question of the impact of climate change on humans.

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Recently, the interpretation of Quaternary paleoclimatic evidence has advanced significantly, particularly in the tropics. Until about 20 years ago, these regions were considered mostly as climatically "stable" and that, during the glacial epochs which affected the mid- and high-latitudes, they were climatically benign. In consequence, the immense variety of plants and animals originated there (see discussion by Colinvaux, 1979). However, increasing evidence has accumulated recently which suggests that the tropics also were affected by important climatic fluctuations during the glacial epochs. These fluctuations were not characterized by glacial advances comparable to those of higher latitudes but, rather, by changes in rainfall and, consequently, in the hydrologic conditions (Fairbridge, 1970; Garner, 1975; Sarthein, 1978). This new tropical paleoclimatic conception generated the hypothesis of biological "refuges" (Fig. 1), originally proposed by Haffer (1969) and Vanzolini (1973). These are restricted zones in which the rich tropical fauna and flora survived during the more severe climate of the glacial epochs (see, for example, the volumes edited by Frande, 1982, and by Whitmore and Frande, 1987). At present, research on tropical paleoecology centers on these refuges, but so far results have been inconclusive as to their existence (Salgado-Labouriau, 1980; van der Hammen, 1982; Liu and Colinvaux, 1985), and some authors have begun to question the refuge hypothesis as it is presently understood (Connor, 1986).

In this preliminary compilation, I will try to establish the paleoclimatology of northern South America and the Caribbean during the last glacial epoch, based on published data, both marine and continental, and on some new data. Although each evidence has only a punctual paleoclimatic value, hopefully, the interpretation of the largest possible amount of such data will confirm the existence of a general paleoclimatic pattern.

Global Paleoclimatology During the Last Glacial Maximum

The maximum advance of the Wisconsin, Würm, or Weichsel Glaciation (Fig. 2), which culminated at approximately 18,000 years B.P. (before the present), is called the Last Glacial Maximum, or LGM (CLIMAP Project Members, 1976). Global conditions during the LGM differed from present-day conditions in the following (CLIMAP Project Members, 1981): 1. a greater extent and volume of continental glaciers; 2. a sea level lowering and a decrease in the oceanic surface; 3. an increase in the area of high-latitude oceanic surface ice; 4. a higher albedo (or reflectivity); and 5. a lowering in the surface temperature of the oceans.

At the LGM (Chörley et al., 1984: 539), global temperatures were between 3° and 6° C lower than today; sea-level was at least 85 m lower; the great ice caps exceeded 4,000 m thickness. In Antarctica 3,000 m in the Arctic; sea-ice was much more extensive than today and cold water emerged in the Atlantic and Pacific Oceans; the temperature gradient was higher along the polar front, which was displaced toward the Equator; the tropical high pressure cells were approximately at their present positions; the continents were much colder and drier than today, with savannas, steppes, and deserts which grew at the expense of forests; and, in particular, the tropics were much more arid than today, with forests—present only in the form of restricted remnants ("refuges") (Fig. 1) within extensive areas of savannas. Mathematical modeling of the atmosphere using ice-age boundary conditions also suggested a significant decrease in rainfall for northern South America (between 730 and 1,825 mm/yr less than today; Manabe and Hahn, 1977). In a compilation of global continental paleoenvironmental data, Peterson et al., (1979) concluded that, for northern South America, the limited data used by them showed evidence for aridity during the LGM, but little qualitative data could be assigned. The aim of this report is to offer a more comprehensive view of paleoclimatic observations (dated and undated) for northern South America.

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Figure 1. Three examples of “refuges” postulated by different authors in northern South America. A. Refuge area of Amazonian fauna and flora (humid tropical forest) during the Quaternary glacial epochs, after Haffer (1969, coarse stipple) and Vanzolini (1973, fine stipple). B. Paleoclimatic zones during the principal glacial epoch in South America (after C. Reforma and J. de Andrade, 1982). The continental limits include those parts of the continental platform exposed during the sea-level lowering (GL: glaciers; MA: mesothermal humid; TA: tropical arid; TH: tropical humid). C. Natural domains of vegetation: 1. cold deserts and Patagonian steppes. 2. Páramo and glaciers. 3. Refuges of humid tropical forest, other forests, and gallery forests. 4. Savannahs, caatingas, cerrados. 5. Coastal and Andean deserts. 6. Scarce undefined vegetation. 7. Open fields, and Araucaria forests. (Simplified after Brown and A. J. S. carle, 1979).
Garner (1959) related the texture of sediments in tropical mountains to the climate, based on modern examples of the Coastal Range of Venezuela and the Andes of Ecuador and Perú. Humid weathering generates fine clastic sediments, which are protected from fluvial and eolian erosion by the plant cover. In contrast, arid weathering generates coarse clastic sediments, which tend to be deposited within the arid region, due to lack of fluvial competence to remove them. Therefore, sediments generated and deposited under arid climates frequently are not completely removed by processes under later humid climates; this Garner termed “sedimentary lag.” The existence of relics of great alluvial fans in the form of spectacular terraces in the Andes, was explained by Garner (1959) as the product of such sedimentary lag phenomena. Huge masses of coarse-grained sediments, deposited under an arid climate, were incised and partially removed under a subsequent more humid climate. A similar conclusion, which supports this hypothesis, was reached in studies of the alluvial terraces in the Venezuelan Andes (Tricart and Millies-Lacroix, 1962). In the northern Venezuelan Andes, within a sequence of four terraces, the second oldest contained wood remnants, which were dated to the middle part of the last glacial epoch (approximately 53,000 14C years B.P., and 45,000 to 47,000 thermoluminescent, or TL, years B.P. on quartz; Schubert and Valastro, 1980; Schubert and Vaz, 1987). The third oldest terrace was dated at 147,000 to 170,000 TL year B.P. (Schubert and Vaz, 1987). In the Eastern Cordillera of Colombia, similar alluvial terrace complexes have been described by Julivert (1959) and Lecarpentier (1971). Ice-age activity in the Venezuelan Andes has also been supported by paleopedological studies (Hetsch and Fölsler, 1979).

In the high zone (páramo) of the Venezuelan Andes, there are two levels of morainic sedimentation: an older one at 2,600-2,800 m elevation, and a younger one at 3,000-3,500 m (Mérida Glaciation; Schubert, 1979). These moraines frequently close the outlets of glacial valleys, in which the classic evidence of Alpine glacial erosion is found: roche moutonnées, whaleback forms, striae and grooves, rock steps, and cirques filled with lakes and peat bogs. The present-day glacial level begins at approximately 4,800 m; between this level and the moraines at 3,000 m is the periglacial region. The youngest glacial advance has been dated as older than 13,000 14C B.P. (Salgado-Labouriau et al., 1977), and possibly 16,000 to 19,000 14C years B.P. (Schubert and Rinaldi, 1987). In the Sierra de Perijá, cirques and remnants of moraines have been described, approximately between 3,000 and 3,100 m (Schubert, 1979).

Three levels of glaciation have been described in the Sierra Nevada de Santa Marta (Colombia): an oldest level, consisting of remnants of moraines at approximately 2,800 m elevation; a principal one (Mamancanaca Stade), above 3,300 m, formed by a spectacular lateral moraines; and a younger level, above 4,500 m, consisting of glacial retreat and neoglacial moraines (Gansser, 1955; Bartels, 1984).

In the Eastern Cordiller—a, van der Hammen et al. (1980/1981) described at least five levels of moraines (between approximately 2,200 and 4,500 m) in the Sierra Nevada del Cocuy. These authors concluded that the maximum glacial advance during the LGM took place before 25,000 years B.P., that is, it is older than the approximately 18,000 year maximum recognized globally, and which reached elevations of 3,000 to 3,400 m. Pollen analyses indicate that between approximately 21,000 and 13,000 years B.P., the climate around Lake Fúquene (Eastern Cordillera) was dry (van Geel and van der Hammen, 1973). Paleopedological studies suggest that during the Late Pleistocene there were several arid phases in the Eastern Cordillera (Fölsler and Hetcsch, 1978).

In the Central Cordiller—a, in the Ruiz-Tolima volcanic complex, glaciers descended to approximately 3,200 to 3,600 m during the LGM, and deglaciation began before 13,000 years B.P. (Herd, 1974). The snow line was lowered by approximately 1,000 m at about 15,000 years B.P. Paleopedological studies in the Central and Western Cordiller—a point to an arid climate during the Late Pleistocene (Fölsler et al., 1977).

Hanging alluvium (remnants of former alluvial fill in steep-sided mountain streams) in the northern flank of the Coastal Range was discovered recently (Schubert, 1985). This alluvium, buried beneath rainforest, filled the channels of rivers and creeks, and has been interpreted as remnants of gravel deposited under an arid climate, due to sedimentary lag. Pedological (Zinck, 1986a, 1986b) and palynological studies (see next section), support a late ice-age aridity in the Coastal Range.
Lake Valencia

Lake Valencia occupies a tectonic depression in the central part of the Venezuelan Coastal Range, whose northern section has been considered a biological refuge (Haffer, 1969). Beneath the lake, there are more than 100 m of lacustrine and fluviatile sediments, which register at least four cycles of lake filling and dessication (Schubert, 1980). Palynological and radiocarbon analyses of a 7.43-m sedimentary core, obtained in the central part of the lake, revealed that before 12,930±500 14C years B. P., the lake did not exist and, between this date and approximately 11,500 years B. P., there was a swamp or intermittent pond (Salgado-Lebouriau, 1980, 1986). At present, the lake covers an area of about 300 km² and has a maximum depth of less than 40 m. This suggests that the climate at the end of the Pleistocene in this region was arid and that a savanna and thorny forest existed in the lake basin. The cloud forest, which today occupies the mountain slopes around the basin above 1,000 m, only reached that position in the Early Holocene. These results are supported by geomorphological and sedimentological studies (Peeters, 1984).

The Llanos

Between the Andes of Colombia and Venezuela to the west, the Coastal Range to the north, and the Guayana Shield to the south, there is a region of low relief and elevation (in general, below 300 m), known as the Llanos. Large fossil dune fields have been detected in this region, which are easily recognized on aerial photographs and satellite images (Tricart 1974 1985; Roa, 1979; Khobzi, 1981; Tricart and Alfonso, 1981). In general, these dunes are modified by erosion and are covered by savanna vegetation. They form a succession of parabolic (partly barkhan) and longitudinal dunes, oriented in a northeast-southwest direction, parallel to the present-day direction of the predominant winds during the dry season. The tails of the parabolic dunes suggest a displacement of several kilometers, and the grain-size implies that the sediment source was homogeneous and stable. Neutron-activation analyses (Herrera and Heurtebise, 1974) indicate that the dune sand had two distinct sources: one in northeastern Venezuela and another in the Guayana Shield, to the southeast. The age of the dunes is apparently Late Pleistocene, as deduced from radiocarbon dating of paleosols beneath them (11,100±450 and 12,300±500 14C years B. P.; Roa, 1979).

Several levels of Pleistocene alluvial terraces, as well as aluvial cones, have been found in the western Llanos (Goosen, 1964; Tricart and Millies-Lacroix, 1962). This type of sediment, commonly made up of gravel, has been explained as a product of torrential sedimentation under a climate more arid than at present and, in the internal valleys of the Andes, in combination with tectonics (Tricart and Millies-Lacroix, 1962; Schubert and Valastro, 1980).

The Guayana Shield

The Guayana Shield consists of outcrops of mainly Precambrian rocks to the north and northeast.
of the Amazonas River. This region, in part within the Amazon Basin, has been the subject of much paleoclimatic speculation, but few detailed studies until very recently. In particular, numerous biologic refuges (for example, the Panapei refuge: Steyermark, 1979), during the Pleistocene arid phases have been postulated (see articles in France, 1982; Brown, 1987). Fig. 1 shows three of these refuges in northern South America. Palynologic studies near a few of these refuges (coastal and Rupununi areas of Guyana, and the eastern Llanos of Colónia), have not confirmed their existence (van der Hammen, 1963, 1974, 1982; Wijmstra, 1971; Wymstra and van der Hammen, 1966; Absy, 1985). Geochemical studies have demonstrated the existence of anomalous drainage patterns in the rivers and the presence of rapids (sulas in Surinam) and terraces along them, all of which have been interpreted as evidence of a drier climate, favorable to alluvial sedimentation and a lower river competence (Bakker, 1968; Garner, 1966; Krock, 1979; Zonneveld, 1972; Tricart, 1975). Eden (1974) described what appear to be savanna refuges within the present-day Amazonian forest; these were interpreted as remnants of a formerly more extensive savanna region, partially maintained at present by burning. Preliminary studies of Quaternary sediments have been conducted recently in the Guayana Shield. On the summits of the Guayana table mountains (cut into Precambrian quartzite of the Roraima Group), there is a thin (less than 3 m thickness), discontinuous layer of peat. This peat is being deposited under the humid, present-day climate, and minimum radiocarbon ages obtained suggest that it began forming in the Early Holocene (5,100 ± 90 to 6,000 ± 80 14C years B.P., or approximately 8,000 years B.P. after correction for contamination; Schubert and Fritz, 1985; Schubert et al., 1986, in press). Palynological analyses of these peat deposits are currently under way (Schubert and Salgado-Labourau, 1987). In the surrounding savannas (Gran Sabana), there are alluvial deposits in the piedmont areas of the table mountains. These deposits, which consist of boulder gravel of quartzite, diabase, jasper, and green chert of the Roraima Group, lie unconformably on rocks of this group and are dissected into at least four terrace levels, up to 30 m high (Schubert et al., 1986). In a diamond placer near the middle reach of the Caroni River, Bricéo (1985) obtained a radiocarbon age of approximately 8,000 years on wood at the base of the deposit. These results suggest that before the Early Holocene, the climate in this part of the Guayana Shield favored mechanical erosion of the table mountains and alluvial deposition, and did not favor peat formation. This is interpreted as evidence for a Late Pleistocene-Early Holocene aridity.

The Lesser Antilles and the northern coast of South America

The Lesser Antilles in this report are defined as all the islands along the volcanic-sedimentary arc that forms the eastern boundary of the Caribbean Sea and the islands along the northern coast of South America, between Puerto Rico and Aruba.
Conflicting Quaternary paleoclimatological evidence has been described in Aruba, Curacao, and Bonaire. Wilhelmy (1954) and Zonneveld (1968) on the one hand described the existence of deep, well-developed arroyos, which suggest a more humid former climate; and Westermann (1931) mentioned the existence of small peat deposits on the islands of Aruba and Bonaire, whose origin he attributed to a more humid climate. On the other hand, de Buissonjé (1974) described abundant eolian deposits on these islands, which are apparently stabilized and imply a formerly more arid climate. None of these features has been absolutely dated; the eolian deposits partially cover the youngest exposed coral terrace that crops out on the islands (approximately 130,000 $^{230}$Th years B. P., Schubert and Szabo, 1978).

In the coastal region of Falcón, the Gulf of Venezuela, and the Guajira Peninsula, other evidence of greater Late Pleistocene humidity have been found: 1. remnants of megafauna, dated at more than 13,000 $^{14}$C years B. P. (Bryan, 1973; Bryan et al., 1978; Ochsenius, 1983; Grunn and Bryan, 1984), also in Curacao (Hooijer, 1967); 2. "fossil" water in aquifers, dated at a maximum of more than 21,000 $^{14}$C years B. P. (Tamers, 1966, 1967); 3. the presence of calcareous crusts in the Guajira Peninsula (Wilhelmy, 1954). It should be pointed out here, that Ochsenius (1983) suggested that the megafauna could have lived under arid conditions, as long as sufficient water holes were present. On the other hand, O. Linares (personal communication, 1987) interpreted the varied fauna of megaherbivores as indicative of a well-developed savanna environment, more humid and less xerophytic than today. He correlated this fauna with that of the Late South American Lujanian age and the Late North American Rancholabrean age. Similarly, P. S. Martin (personal communication, 1987) doubted the usefulness of any of a reliable paleoclimatic indicator. Geomorphological evidence suggests that, due to sea-level lowering during the LGM, the Lake Maracaibo Basin was a closed basin, and that the channel which connects it with the Caribbean Sea was excavated during more arid conditions than at present (Sarmiento and Kirby, 1962). On the basis of sedimentological studies, Graf (1969) suggested that the glacial epochs corresponded to times of greater humidity in the Lake Maracaibo Basin and the Gulf of Venezuela.

On the island of La Orchila, there are remnants of dunes whose surface has been cemented by calcium carbonate recrystallization, and which have been stabilized by xerophytic vegetation (Schubert and Valastro, 1976). These remnants are on a coral terrace whose age is approximately 130,000 $^{230}$Th years B. P.

On the islands of Antigua and Barbuda (northeastern Lesser Antilles), fossil remnants of the owl *Athena curiculata* have been found. This is a species typical of xerophytic regions, and the remnants were found in sediments attributed to the Late Pleistocene (Pregill and Olson, 1981). According to these authors, on the islands of Antigua and Marie Galante, this owl became extinct in recent time.

**Central America and Mexico**

Palynological studies in Panamá (Gatún Basin) have revealed that between approximately 35,000 and 11,300 years B. P. there was no sedimentation (probably due to sea-level lowering during the LGM), and that 35,000 years ago, the temperature was approximately 2.5°C lower than today (Bartlett and Bargoorn, 1973). Between 11,300 and 9,600 years B. P., the post-glacial mangrove invasion began, although pollen from high altitude plants was still found, suggesting that the temperature was at least 2.5°C less than today.

In the Cordillera de Talamanca (Costa Rica), there are moraines at approximately 3,500 m elevation, implying an important glacial advance during the Late Pleistocene (Hastenrath, 1973; Barquero and Ellenberg, 1986). Palynological study of a 13-m lake core (including four radiocarbon dates) has shown that, at 2,400 m elevation, páramo and montane rain forest vegetation alternated (Martin, 1964). The last cold phase lasted from more than 36,000 to about 10,000 $^{14}$C years B. P.; during this phase, the lake level was high and it progressively became a marsh and later a peat bog during the Holocene. In the valley of the General River, several alluvial surfaces have been described (Kesel and Spicer, 1985), which show progressively greater soil development with age. These deposits could represent deposition under a drier climate, although they were interpreted (based on soil development and the Quaternary uplift of the Cordillera de Talamanca) as of tectonic origin under a humid climate.

In the Altos de Cuchumatanes (Guatemala), remnants of moraines have been described at approximately 3,500 m (Hastenrath, 1974). In the Petén Department, a palynological study of low-altitude lakes (Leyden, 1984) suggests that before approximately 10,750 years B. P. these lakes were swamps and were surrounded by savanna. Similarly, there is palynological evi-
The evidence of the former existence of savanna in the Yucatán Peninsula (Toledo, 1982).

In the Transmexican Volcanic Belt, much evidence of Pleistocene glaciation has been described, well dated by tephrochronology and radiocarbon dating (Heine, 1976; White, 1986). The Late Pleistocene lowering of the climatic snowline could have been as much as 1,300 m. Although the variation of temperature and rainfall has not been established quantitatively, the evidence suggests a relatively arid phase between approximately 30,000 and 15,000 years B.P.; after this, several precipitation fluctuations were observed, and after approximately 9,000 years B.P., rainfall gradually adjusted to present-day values.

Greater Antilles

Recently, Ortega and Arcia (1982) published a review of the pedological evidence for climatic change in Cuba (carbonate, silica, and gypsisiferous remnants, and other characteristics of the red ferrallitic Cuban soils), and concluded that all this evidence suggests a formation under a climate more arid than today, with precipitation under 800 mm/yr, and possibly not greater than 400 mm/yr. Similarly, the presence of phosphates and eolian deposits (also described by Duclouz, 1963, and Shanzes et al., 1975) supports the former existence of a drier climate. Based on these data, Ortega (1983) presented a paleoclimatic map of Cuba, in which he shows that during the last glacial epoch, the climate was...
predominantly that of a warm steppie (sahelian), with desert areas in the east and coastal regions. On the other hand, Rodrigues et al. (1984), in a review of finds of Holocene Cuban edentates, published a list of bone radiocarbon ages which suggest a maximum mid-Holocene age. The presence of these animals could be explained by a more humid post-Pleistocene climate.

In the Dominican Republic, remnants of a Pleistocene glaciation have been found in the Cordillera Central (Schubert and Medina, 1982). The geomorphic features (morainic remnants and cirques) indicate a Pleistocene snowline between 2,300 and 2,500 m elevation. Considerations about the change in the temperature gradient due to this lowering of the isotherms suggest that this gradient could have been larger than 1° C/100 m. This change, in turn, implies a more arid climate than today. In the Ocoa River valley, there is an alluvial terrace complex, which is interpreted as due to torrential deposition under a drier climate.

Studies of beach deposits in Puerto Rico suggest substantial climatic changes in the Pleistocene, indicated mainly by changes in the composition, quantity, and grain-size of the sediments (Carbone, 1980). On Mona Island, there are speleothems and guano deposits, in which the mineral brushite (hydrated form of CaHPO₄) was found; this mineral forms below 25°C. None of these features has been absolutely dated.

Among the present-day insects and amphibians of Jamaica, there is a large proportion of savanna species. This has been interpreted as a remnant of a former arid climate (Buskirk, 1985). Prell and Olson (1981) described the present-day and Pleistocene distribution of numerous animals in Florida, the Bahamas, the Greater Antilles, and the northeastern Lesser Antilles. A large number of these animals, for example the owl Athene curicuraria, are characteristic of xerophytic environments. Their present-day distribution could be relictual if an arid habitat existed before.

Marine regions

In the marine regions of the Caribbean, Gulf of Mexico, and the Atlantic continental borderland of northeastern South America, many sedimentary cores have been obtained for mineralogic and micropaleontologic analyses. Damuth and Fairbridge (1970) published a pioneering study in which they analyzed mineralogically sedimen
tary cores obtained on the continental borderland to the southeast of the Orinoco River delta. The Pleistocene-Holocene transition was found in 39 cores. The Pleistocene sands contained a higher percentage of feldspar (25-60%) with respect to the Holocene sands (17-20%). This was interpreted as a consequence of Pleistocene erosion under a drier climate than today, which did not favor weathering. Similarly, Bonatti and Gartner (1973) found mineralogical evidence in Pleistocene detrital sediments from the central part of the Caribbean Sea, for an arid sedimentary source.

Palynological studies of the continental platform east of the Orinoco River Delta (Muller, 1959) suggested that the coastline was far to the east 17,820 years B. P., with a very reduced mangrove pollen content with respect to the present-day situation.

Foraminiferal analyses of numerous sedimentary cores from the bottom of the Caribbean Sea, show that during the glacial epochs (for example, the LGM, about 18,000 years ago), the sea surface temperature was 2° to 3°C lower than during interglacial times (Prell et al., 1976). A similar temperature lowering was found for the LGM in the Gulf of Mexico (Beard, 1973).

Conclusions

This brief review of the main paleoclimatological evidence found in the Caribbean Sea and adjacent regions, in general suggests that, during the LGM, the climate of all of this region was more arid than today. In northern South America, a large amount of data has accumulated which permits the very tentative differentiation of two climatic sub-regions (Fig. 6): one with an extreme aridity (the Venezuelan and Colombian Llanos), relatively well dated, and another with a more humid climate than today (Lake Maracaibo Basin, north of Falcón, and the islands of Aruba, Curacao and Bonaire), without reliable dates.

The rest of the region studied shows punctual evidence of aridity during the LGM, which makes it difficult to make inferences about the degree of aridity. It is estimated, in general, that there existed a tropical savanna climate, with alternating yearly humid and arid phases (the "climatic dry savanna" of Walter, 1973: 323, which is characterized by an annual dry season of 5 to 7 months). The limits of the altitudinal ecologic zones were lowered by several hundreds of meters, and each zone (in a descending order), was compressed in its vertical extent due to the increase in the temperature gradient for the average rate; mean sea-level temperature was approximately 2° to 3° C lower and possibly 6° C at high elevations than today.

Another important problem is the relative lack of reliable absolute dating. In this compilation, I tried to utilize to a maximum that evidence whose chronology is well established (this is reflected in the symbolic quality assessment in Fig. 6, No. 14). However, large expanses have only provided qualitative data. The Caribbean region is in large part submerged; therefore, paleoclimatic data from these parts is limited to paleontological analyses, which reflect mainly changes in the sea surface temperature.

Finally, the few paleoecological studies undertaken in northern South America and the Caribbean have failed; to document the existence of Pleistocene biological refuges. In particular, the Lake Valencia area, located within the Coastal Range refuge, supported a dry, thorny forest, and the lake basin was dry, or, at best, contained a swamp. This example shows that many more paleoecological studies are necessary, particularly in those regions populated as refugees, in order to document their existence, and study how these refuges functioned.

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APPENDIX D

Climate Variability and Climate Change
The Role of a Small Island State, for Instance, Trinidad and Tobago

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Introduction
Within the last decade, a number of events occurred to bring to centre stage the global issue of climate change. Broad classifications of episodes of great significance may include: (1) the frequency of natural events (floods, droughts, tropical revolving systems); (2) the warming observed in the 1980s labelling the decade as the warmest in 80 years (1988 being the warmest); (3) depletion of the ozone layer in the Antarctic region (in October 1987, the ozone values fell to the lowest); and (4) mean sea level rise. Each of these phenomena have negative environmental impacts.

Lots of discussions at international fora have taken place during the last two years. The question has been asked "Has man already begun to alter earth's climate?"

The contention though is whether the recent changes observed are a result of natural climatic variability or, due to increased concentration of greenhouse gases, a result of the expansion of the world's economic system.

Climate modelling and careful analysis of observational records provide the wherewithal for the study and prediction of the complex interplay between the various processes that are important for the climate system and climate change. In the atmosphere these processes include the interactions and feedbacks between clouds and radiation, the land surface and the atmosphere and the atmospheric boundary layer, and the exchange of properties between sea and air. Ultimately this will lead to a better understanding of the mechanisms underlying climate variations.

Short term climate variability is affected by: (1) world sea surface temperature anomaly patterns which exercise considerable control over seasonal rainfall in various tropical regions and (2) coupling between the ocean and atmosphere which can occur on a variety of time scales. It is particularly strong and fast in the tropical regions where it manifests itself, in particular, as in the El Niño events.

The biggest uncertainty in linking the observed warming with increased greenhouse gases concerns the effects of possible changes in the nature and distribution of clouds. Clouds have a profound climatic effect: they both cool the earth-atmosphere system by reflecting solar radiation back to space and warm the system by reducing the effective radiating temperature of the planet.

Climate is shown to be sensitive to land surface alterations, for example, in deforestation (the Amazon rain forests) and desertification. Increased temperature and reduction of rainfall have been noted.

Regional Nature of the Problem
In the Caribbean, made up of small island states with limited resources and industries, the contribution to global pollution is indeed negligible. Then, too, the trade wind flow, which is strong throughout the year except in the southern islands during the wet season (Trinidad and Tobago included), transports continuously westward across the Caribbean seas whatever pollutants that escape into the atmosphere or are advected from African or European sources.

The Caribbean's concerns are:

1. the apparent increase in high intensity hurricane activity becoming even more frequent in time and spreading to more southern latitude regions. Jamaica's experience with Hurricane Gilbert (1988) and Hurricane Hugo's onslaught of the Northern Leewards are indeed testimony to the potential destruction of these high intensity tropical revolving storms. Disaster preparedness has taken on renewed importance for many of the islanders who would recall the trauma of their neighbours.

2. Since the islands are surrounded by the vast Atlantic ocean and the Caribbean sea, the role of the ocean, heat flux, and ocean-atmosphere coupling may be very important in the medium and long term,
as a vehicle for climate variation. The sub tropical Atlantic studies of NOAA, which is a multi-investigator, multi-institutional program (Molinari, 1990), is directed at: (a) increased understanding of the role of the western boundary currents of the Atlantic ocean in meridional oceanic heat flux, and (b) development of strategies to monitor important western boundary features with additional effort being directed at the annual and inter-annual signals because of their possible relevance to climate problems.

The Present Efforts of the Government of Trinidad and Tobago

The issue of climate change is receiving the attention of the government of the country. More emphasis is being placed on environmental matters including the recent focus on the development of an Environmental Information System to harness all information throughout the country related to the environment. This information pool can serve various agencies that have to make decisions or statements on the environment, especially as it related to climate variation.

Trinidad and Tobago was represented at the Ministerial Conference on Atmospheric Pollution and Climate Change held in the Netherlands during November 1989 and also at the Small States Conference on Sea Level Rise in the Republic of the Maldives later that month. The recommendations from the delegation, which were agreed to by the Cabinet included:

(1) convening a task force that is to identify sources of atmospheric pollution from industries and to determine means of reducing their pollution. Data are being collected at present to quantify the pollutants from oil industries, quarrying operations, power plants and other industries which in the course of their operations release effluents into the atmosphere. Sources of chlorofluorocarbons are especially targeted for reduction in accord with the Montreal Protocol. The action of the wind system and precipitation and the stability criteria on these atmospheric pollutants are being analyzed to determine how they are displaced in time (Dunn, 1987).

(2) establishing a working group to determine the implications for Trinidad and Tobago of global warming, climate change, and sea level rise. The group is seeking to analyze all available data on tide gauge measurements throughout the country and to have all pertinent meteorological and climate information available to it and to identify fragile coastal ecosystems.

Trinidad and Tobago with its limited financial resource base is intent on assisting wherever possible in the reduction of atmospheric pollution. Its own environmental agenda will include:

(1) a programme for the management and conservation of mangrove areas be developed;
(2) a project for replanting coral reefs; and
(3) a reforestation programme.

Coastal zone management with sea defense attributes and providing sinks for carbon dioxide are the objectives of the agenda.

Meteorological Concern

The Meteorological office is concerned with the following episodes:

(1) the prevalence of the Sahara dust during the dry season within recent times. Is this phenomenon increasing due to the spread of the desert, or are we becoming more aware of its presence due to better weather satellite imagery?

(2) mini-tornado, October 1988 (Maharaj, 1988). A tornado has not been sighted for many decades in Trinidad. Occasionally, waterspouts are observed. Recall that 1988 was the warmest year since the late 19th century.

(3) increased riverine flood frequency due to intense rainfall experienced over consecutive days. Trinidad was affected by severe floods in 1981, 1985, and 1988. Rainfall frequency analysis has indicated that these intense rainfall episodes have increased during the last decade (Henry, 1987).

(4) extremely dry dry-seasons in 1987 and 1988 putting pressure on our water resources.

Are these episodes a result of climate variability or climate change? The available records are too short to make an informed pronouncement.

Analysis of mean annual surface temperature revealed a gradual warming, using data from 1946 to 1989, albeit only for Piarco Airport. Rainfall patterns have changed over time with areas of high rainfall relatively now having higher mean annual rainfall. The last four months of the year appear to be the period with greatest incremental change, whilst the rainfall during the first four months is randomly varying with a
high coefficient of variation (0.40). The rainfall pattern during the middle four months (May through August considered to be the core of the rainy season) is somewhat steady considering the graph of 30-year moving average of the rainfall data (coefficient of variation approximately 0.20). Areas of low rainfall, which include the west coastal areas, have remained relatively steady over time and for the three periods of the year noted above. The upper atmosphere has shown on the average some measure of warming within the last two years. We are using monthly long term mean for mandatory levels (1976 - 1987) and compute anomalies for subsequent months. Studying the changes in water vapour content or the changes in the ratio of water vapour to sea level pressure may give us further clues in our continuing search for trends in the climatic variables.

The Meteorological office is conscious of its role in providing quality controlled data to the regional and international community and has installed the CLICOM system, which is gaining in popularity worldwide. Soon, our network of data will expand with the acquisition of eight automatic weather stations with a variety of sensors including radiation, temperature (both ambient air and soil), wind, rainfall, etc. All data will be available to regional and international researchers and climate modellers.

We will keep abreast of information disseminated by the World Climate Programme, the work of the Intergovernmental Panel on Climate Change, and research results contained in various climate journals. We do not have the resources to be involved in climate modelling at this time.

Conclusion
We are convinced that our plans during the next decade will not bear fruit if climate impacts on the various weather sensitive sectors of our economy and environment are not given the consideration they deserve. Particular attention should be given to strategic planning, with its long term objective being conservation of the environment. Profit maximization and risk minimization (Eddy, 1989) should take into account the estimates of extreme event frequencies as may be inferred from various models and simulations.

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