SAND 91-1927C

SAND--91-1927C

DE92 006807

AN OVERVIEW OF THE YUCCA MOUNTAIN GLOBAL/REGIONAL CLIMATE MODELING PROGRAM

Robert P. Sandoval
Sandia National Laboratories
P. O. Box 5800, Div. 6316
Albuquerque, NM 87185
(505) 844-1970

Yugal K. Behl
GRAM, Inc.
8500 Menaul Blvd., NE
Albuquerque, NM 87112
(505) 299-1282

Starley L. Thompson
National Center for Atmospheric Research
P. O. Box 3000
Boulder, CO 80307
(303) 497-1628

I. INTRODUCTION

The U.S. Department of Energy (DOE) has developed a site characterization plan (SCP) to collect detailed information on geology, geohydrology, geochemistry, geoengineering, hydrology, climate, and meteorology (collectively referred to as "geologic information") of the Yucca Mountain site[1]. This information will be used to determine if a mined geologic disposal system (MGDS) capable of isolating high-level radioactive waste without adverse effects to public health and safety over 10,000 years, as required by regulations 40 CFR Part 191 and 10 CFR Part 60, could be constructed at the Yucca Mountain site.

In the SCP, the geologic information needs have been grouped under various programs, the climate program being one of them. The investigations, studies, and activities within the climate program are designed to provide information on past, present, and future climate conditions, and to estimate the effects of future climate on surface, unsaturated-zone, and saturated-zone hydrology. One of the studies in the climate program is the Characterization of the Future Regional Climate and Environments. The purpose of this study is to predict future climate conditions in the southern Great Basin for the long-term performance assessment of any proposed MGDS as a potential nuclear-waste repository at the Yucca Mountain site. Specifically, this study would provide the range of values of key climate parameters (precipitation, temperature, and evapotranspiration) which, in combination with other relevant geologic parameters, could be used to estimate fluctuations in water tables and ground-water travel rates for the Yucca Mountain area over the next 10,000 years.

Forecasts of future climate conditions for the Yucca Mountain area will be based on both empirical and numerical techniques. The empirical modeling is based on the assumption that future climate change will follow past patterns. In this approach, paleoclimate records will be analyzed to estimate the nature, timing, and probability of occurrence of certain climate states such as glacials and interglacials over the next 10,000 years. For a given state, key climate parameters such as precipitation and temperature will be assumed to be the same as determined from the paleoclimate data. This activity is being performed by another organization and, therefore, will not be discussed further in this paper.

The numerical approach, which is the primary focus of this paper, involves the numerical solution of basic equations associated with atmospheric motions. This paper describes these equations and the strategy for solving them to predict future climate conditions around Yucca Mountain.

II. TECHNICAL APPROACH FOR REGIONAL CLIMATE MODELING

A. Basic Equations

The basic equations governing the behavior of the atmosphere are the classical fluid dynamic partial differential equations expressing conservation of mass (continuity equation), momentum (Navier-Stokes equations), and energy (first law of thermodynamics) as applied to a rotating sphere. These equations are shown in Table 1, along with diagnostic relationships for internal energy and the thermodynamic state. Various physical processes controlling atmospheric behaviors, such as insolation and viscous drag, are incorporated in heating and frictional terms.

These equations, together with proper boundary conditions, form a complete set. Therefore, in principle, given the atmospheric conditions at some initial time, these equations can be solved to determine the atmospheric conditions at any future time. In practice, one is not interested in instantaneous atmospheric conditions, but rather in average conditions over some time period Δt. The atmospheric conditions constitute the "weather" when the averaging period is on the order of a few hours and the "climate" when the averaging period is on the order of a month or longer.

Table 1. Basic Equations Governing the Behavior of Atmospheric Motions

mass:

$$d\rho/dt = -\rho \nabla \cdot \mathbf{V} \quad (1)$$

momentum:

$$d\mathbf{V}/dt = -(1/\rho)\ \nabla p\ -\ \nabla \Phi\ -\ 2\ \Omega \times \mathbf{V} + \mathbf{F}_{fric} \quad (2)$$

energy:

$$de/dt = (p/\rho)\ \nabla \cdot \mathbf{V} + q \quad (3)$$

plus the diagnostic relations

$$e = c\,T \quad (4)$$
$$p = \rho R T \quad (5)$$

where ρ is the density; p is the pressure; T is the temperature;

$\mathbf{V} = u\mathbf{i} + v\mathbf{j} + w\mathbf{k}$
$u = a \cos \phi\ d\lambda/dt$ (eastward speed),
$v = a\ d\phi/dt$ (northward speed),
$w = dz/dt$ (vertically upward speed),

$\mathbf{i}$, $\mathbf{j}$, $\mathbf{k}$ are the unit vectors eastward, northward, and upward, respectively; λ is the longitude; ϕ is the latitude; z is the vertical distance; t is the time; a is the radius of the earth;

$$\nabla = \mathbf{i}\ \partial/a \cos \phi\ \partial\lambda + \mathbf{j}\ \partial/a\ \partial\phi + \mathbf{k}\ \partial/\partial z$$

$$\Phi = g\ z$$

g is the acceleration due to gravity; Ω is the angular velocity of the earth; F_{fric} is the atmospheric viscous drag term; q is the rate of heat addition per unit mass due to radiation, conduction, phase changes, and viscosity; e is the internal energy; c is the specific heat at constant volume; R is the gas constant for air;

$$d/dt = \partial/\partial t + \mathbf{V} \cdot \nabla$$

B. Regional Climate Modeling Approach

Over the years, many computer climate models have been developed to numerically solve the basic equations with varying degrees of sophistication. The most sophisticated of these models are the general circulation models (GCM) which solve the atmospheric equations in 3-d and typically include most of the physical processes believed to be important. However, even various GCMs have distinct features. For example, GCMs account for oceans in many different ways, such as: 1) prescribing distributions of sea-surface temperatures (SSTs) and sea ice; 2) representing the upper ocean by a 50-m thick thermodynamic slab; or 3) solving coupled oceanic and atmospheric equations. Since coupled ocean-atmosphere GCMs are still highly experimental and computationally demanding, GCMs quite often use one of the first two approaches to account for oceans in various applications; fortunately, the models seem to do an adequate job.

Currently, it is not practical to run GCMs at higher resolution to simulate the effect of topographical features such as mountain ranges, large lakes, and coastlines. For example, the Community Climate Model (CCM) of the National Center for Atmospheric Research (NCAR) would take about 1.5 days of CPU time (CRAY X-MP) per simulated day to provide a 50-km resolution[2].

In the past several years, a number of research efforts have been started to address the inadequacy of GCMs to simulate regional climates.

One such effort at NCAR involves nesting a high-resolution regional climate model (RCM) in a GCM over a selected area of interest. In this approach (one-way-nesting technique), a GCM is run for a selected period of interest. The GCM output (wind, temperature, surface pressure, water vapor mixing ratio, SST, temperature and water content of the soil, and CO_2 and O_3 concentrations) is interpolated to provide initial and time-dependent boundary conditions for the RCM at each RCM time step over the selected region of interest (called domain). The RCM output provides the high-resolution regional climate for the selected period of interest. Preliminary results of one-way-nesting technique applied over different regions of the world have been encouraging[3,4,5].

C. Regional Climate Model

The RCM being used in this study is an augmented version of the NCAR/Penn State Mesoscale Model 4, or MM4. The standard version of MM4 is described in detail by Anthes et al.[6] It includes the bulk boundary layer formulation of Deardorff[7], a version of the force-restore scheme for the ground temperature calculations[8], the cumulus parameterization of Anthes[9] coupled to instantaneous precipitation of condensed water in stable environments, and a simple scheme for longwave radiative cooling. The augmented version of MM4 has the same structure as the standard MM4 except that it includes some new features which are summarized below:

- The augmented MM4 has a sophisticated surface physics-soil hydrology package called the Biosphere Atmosphere Transfer Scheme (BATS). The scheme comprises a vegetation layer, a snow layer, a surface soil layer 10 cm thick, and a deep soil layer, or root zone, 1-2 m thick. Currently, BATS can describe 15 vegetation types, soil textures ranging from coarse (sand) to intermediate (loam) to fine (clay) and different soil colors (light to dark) for the soil albedo calculations. BATS is described in detail by Dickinson et al.[10]

- The use of BATS requires an explicit boundary-layer representation in which the height of the lowest atmospheric level is a few tens of meters. The augmented MM4 has five levels in the lowest 1.5 km of the atmosphere, at approximately 40, 110, 310, 730, and 1400 m above the surface.

- To facilitate coupling with BATS, a more detailed radiative transfer scheme developed for the NCAR Community Climate Model has been incorporated in MM4. The package is described in detail by Kiehl et al.[11].

- At a given grid point, clouds are defined in terms of a fractional cloud cover using the parameterization of Slingo[12]. The thickness of a cloud layer is assumed to be equal to that of the model layer and the cloud water content is equal to 0.5 grams/cubic meter for middle and low clouds (pressure > 420 mb) and 0.1 grams/cubic meter for high clouds (pressure < 420 mb).

D. General Circulation Model

GENESIS is the GCM selected to determine boundary conditions for the regional climate simulations. GENESIS was developed by the Interdisciplinary Climate Systems (ICS) section of the Climate and Global Dynamics Division of NCAR, which started the Global Environmental and Ecological Simulation of Interactive Systems (GENESIS) Project in 1987 to develop a global climate model especially suited for studies of long-term climatic changes such as those required for the Yucca Mountain Site Characterization Project (YMP). To meet this objective, major new features such as a diurnal cycle, semi-Lagrangian transport of water vapor, a new solar radiation code, a comprehensive (20,000 lines) land-and-surface module that includes detailed vegetation effects, and a mixed-layer ocean module with dynamic sea-ice were added to the NCAR Community Climate Model Version 1 (CCM1). The resulting upgraded code has been named, appropriately, GENESIS. In the climate modeling program, GENESIS actually will be run by another organization, which will provide the boundary conditions to NCAR for the regional climate model simulations.

E. Strategy for Long-Term Climate Simulation

Given that a GCM at a resolution of 500 x 600 km takes 6 CPU hours on a CRAY X-MP and MM4 at a resolution of 60 X 60 km takes 90 CPU hours to simulate the regional climate over one year, it is not practical to run these models to simulate climate for a period of 10,000 years. Therefore, a more limited strategy has been adopted which considers only worst-case scenarios for the Yucca Mountain area.

The arid climate around the Yucca Mountain region is one of several factors which make Yucca Mountain attractive as a potential site for radioactive-waste disposal. However, paleoclimate records of the southern Great Basin indicate that this region has experienced extremely varied climate in the past. Specifically, paleoclimate data suggest that the southern Great Basin experienced significantly higher levels of precipitation during certain global climate states such as glacials and interglacials. These states have finite probability to recur over the next 10,000 years, with an associated increase in precipitation around Yucca Mountain.

Based on these observations, the following approach has been adopted:

- Paleoclimate data will be used to identify as many scenarios as possible with high levels of effective moisture (precipitation minus evaporation).

- Energy-balance models will be run for these scenarios of high effective-moisture levels to select a subset of worst-case scenarios and to narrow the simulation period to 3-5 years for these scenarios[13]. These runs have been made and a set of scenarios has been selected (Table 2).

- For these scenarios, a database of the key parameters will be developed: seasonal insolation at the top of the atmosphere, atmospheric greenhouse gas composition, ice volume and placement, and SSTs. These parameters are used as initial and boundary conditions for the GCM.

- GENESIS and MM4 will be validated using the paleoclimate database (see Section IV). Additional validation analyses are planned for MM4 (see Section III).

- GENESIS and MM4 will be run using the one-way-nesting approach for each scenario (simulation period ~3-5 years). The MM4 output provides the range of values of key climate parameters that might be expected over the next 10,000 years at the Yucca Mountain site. See Section IV for schedule.

The first three steps in the strategy below are being performed by another organization, and are not discussed in this paper.

Table 2. A Preliminary List of Scenarios for Future Climate Forecasting

1. 18K BP Full Glaciation Ice Scenario
2. Pre-18K Intermediate Ice Scenario
3. Super-Glacial Ice Scenario
4. 2x Present CO_2 Scenario
5. 2x Present CO_2 with Reduced North Atlantic Downwelling Scenario
6. 4x Present CO_2 Scenario
7. 8x Present CO_2 Scenario
8. Extreme SSTs Scenario

K=1000 years and BP=before present

III. PRELIMINARY VALIDATION ANALYSES OF MM4

Because MM4 was originally designed and used for weather forecasting, additional validation analyses are being performed to evaluate the code and quantify the uncertainties for climate applications. These validation analyses consist of two phases. The first phase analysis was performed to characterize the performance of MM4 as a tool for simulating regional climate under conditions close to those at present. The results of this analysis are the subject of two papers submitted for publication by other researchers. Some selected results are presented below.

In the second phase, the RCM will be run for a cumulative time of not less than five years using boundary conditions from GCM simulations of a present-day climate scenario. This phase will determine whether a RCM using boundary onditions from a GCM for lengthy time periods will produce reasonable climates.

A. Selection of Simulation Periods

Two multi-year simulation periods were selected for the validation of MM4: the two-year period from January 1982 to December 1983 which included a pronounced El-Niño event[14] and was characterized by wetter than, and somewhat warmer than, normal conditions over most of the west; and the 16-month period from January 1988 to April 1989 during which drier than normal conditions prevailed over most of the continental U.S., with annual precipitation in 1988 less than 75% of normal in most of the west.

B. Model Input

The domain used in MM4 centered over the Great Basin and covered a 3300 km x 3000 km area including the western U.S., northern Mexico, and adjacent ocean waters (Figure 1). The horizontal grid point spacing is chosen to be 60 km. At this resolution, the model topography shown in Figure 2 appears to capture prominent features of the western U.S. topography and coastline, such as the Sierra Nevada, the Cascades, the Rocky Mountains and the Gulf of California.

Sea-surface temperatures were obtained by interpolating from the global 2-degree monthly SST dataset of Shea et al.[15] onto the MM4 grid. Meteorological initial and boundary conditions (wind components, temperature, water vapor mixing ratio, and surface pressure) that were used to drive the model runs were interpolated from a European Center for Medium Range Weather Forecasting (ECMWF) global database[16].

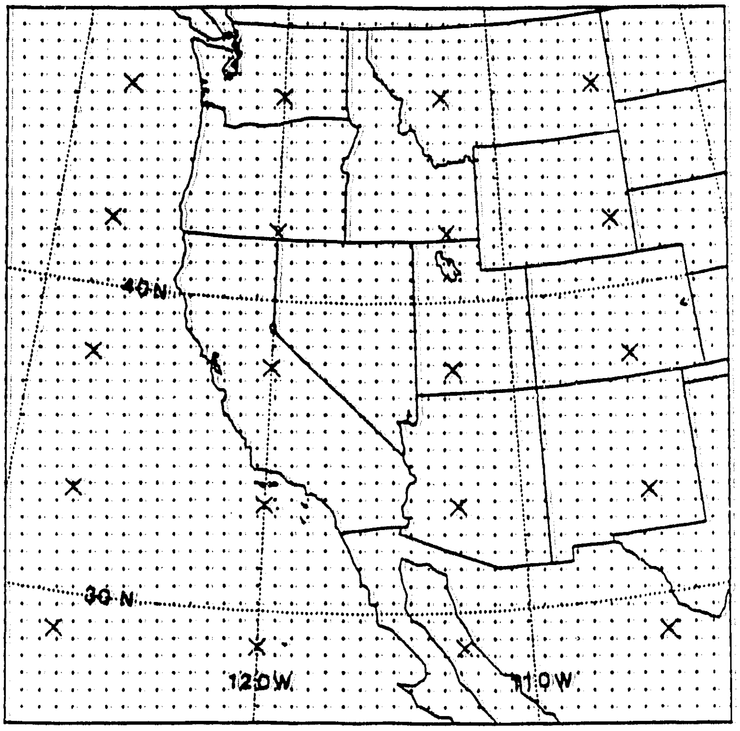

Figure 1. The western U.S. domain used in the Mesoscale Model 4 (MM4) for regional climate analyses. Small dots mark the locations of regional model grid cells (60 x 60 km resolution). Crosses mark the location of grid cells in a typical GCM (in this case, the NCAR CCM1 at 4.5 x 7.5 degree resolution)

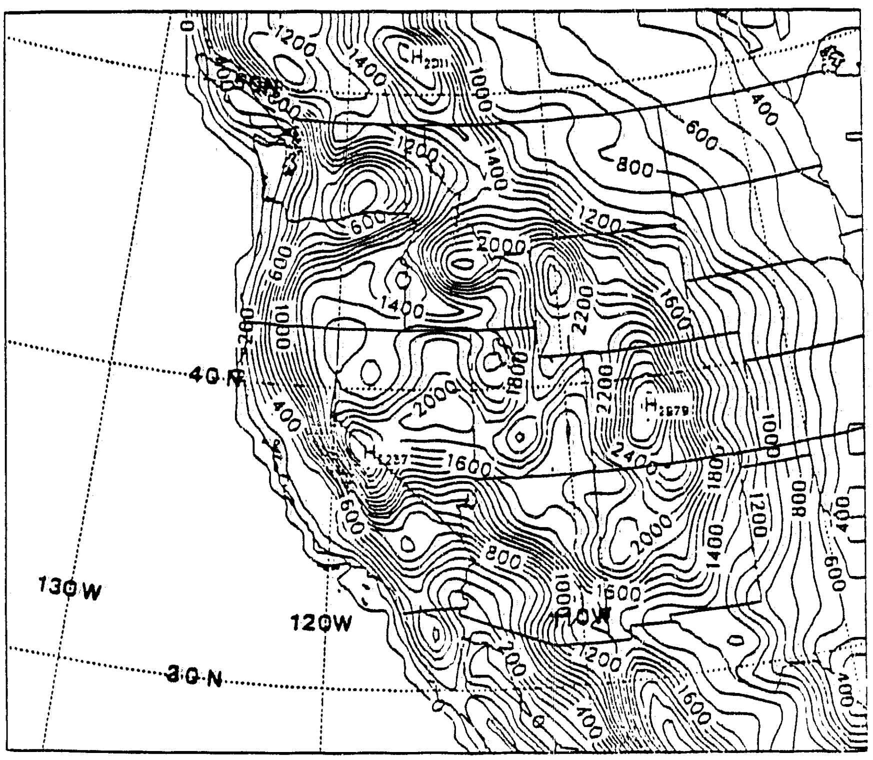

Figure 2. Topographic contour map of the western U.S. domain used in MM4. Contours are in meters at 100-meter intervals.

The details of the interpolation schemes used are discussed by Giorgi and Mearns[2].

C. Measured Data

The model results were compared with the observed data from 390 stations distributed over the western U.S. and available from the National Climatic Data Center in Asheville, North Carolina. Variables used in the model validation are daily maximum and minimum near-surface air temperatures and precipitation.

D. Preliminary Results for Temperature

Selected results are shown in Figures 3 and 4. In Figure 3, modeled and observed values of monthly averages of daily maximum and minimum temperatures are compared for both simulation periods. The averages in Figure 3a are based on all 390 stations. The agreement between model results and observations is quite good. Figure 3b shows the model and observed averages for five stations near the Yucca Mountain site: Amargosa Farms, Beatty, Key Pittman, Las Vegas, and Tonopah. Overall, the model reproduces seasonal temperature cycles reasonably well, however, the model temperatures are consistently lower than the observed temperature by up to 1-4 ^{0}C. These differences may be attributed to the fact that all five model grid points are at higher elevations than the observing stations by about 200 to 500 m. In Figure 3c, similar differences are observed for the station, Beatty, which is the nearest observing station (about 30 km) to the Yucca Mountain site.

IV. SCHEDULE

The validation analyses discussed in Section III will be completed by the end of FY 92. The paleoclimate validations of both GENESIS and MM4 are targeted for completion by the end of FY 93. The future climate forecasts activity will begin in FY 94 and is expected to take about 2 years to complete. These target dates are tentative and may change due to fluctuations in the funding.

V. CONCLUSIONS

In summary, preliminary results of a validation analysis performed to characterize the capability of the regional climate model (MM4) to simulate selected key regional climate conditions at the Yucca Mountain site indicate relatively good performance of the model. The range of values for precipitation and air temperatures forecasted near the site surface for the simulated periods compares well with observed data for those periods. The results presented in

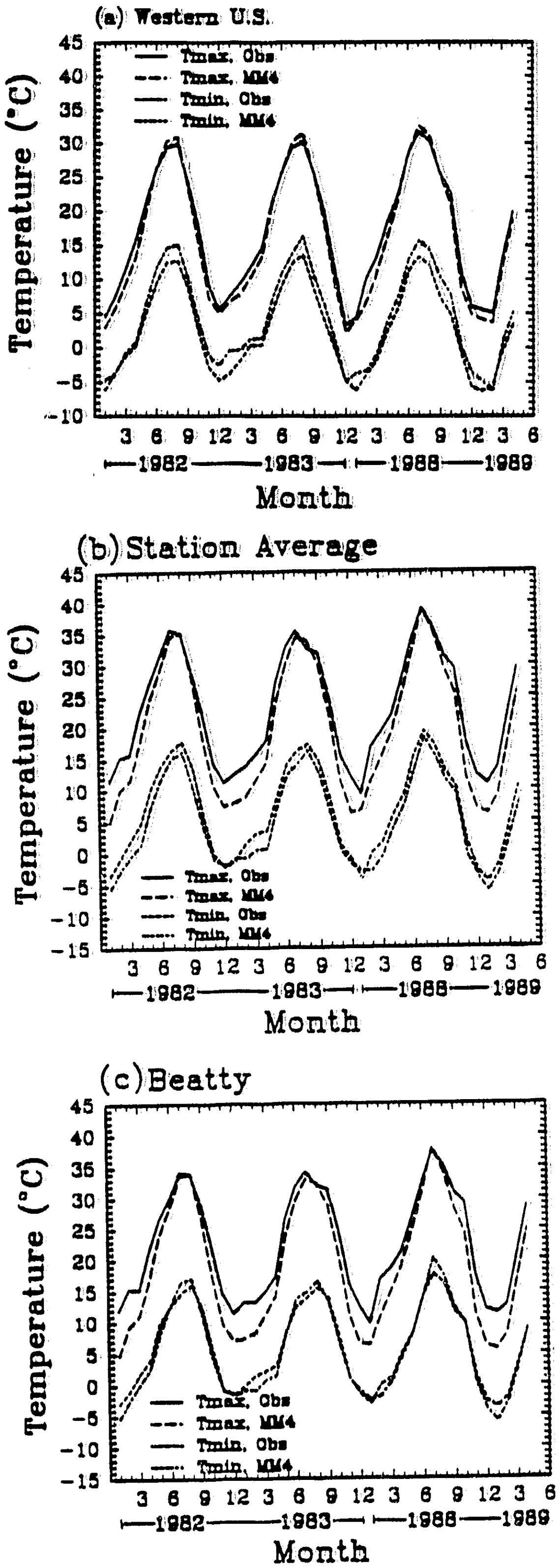

Figure 3. Monthly averages of modeled and observed daily maximum and minimum temperature for (a) 390 stations, (b) 5 stations near the Yucca Mountain sie, and (c) 1 station (Beatty, Nevada).

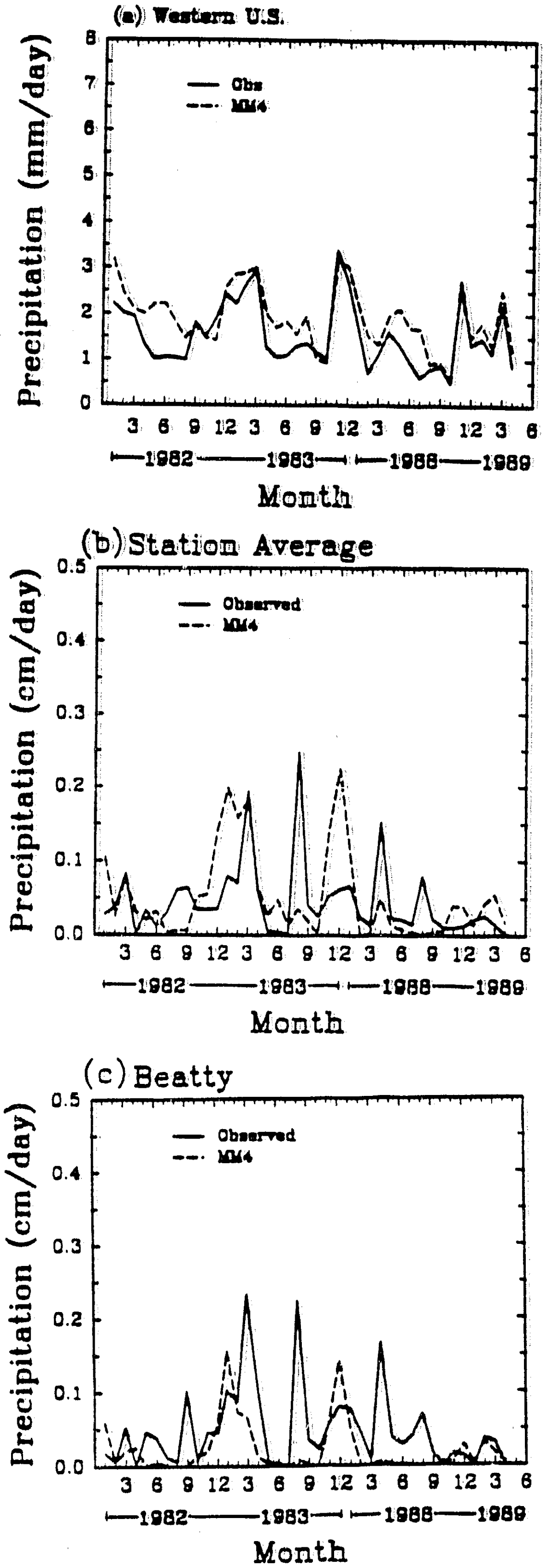

Figure 4. Monthly averages of modeled and observed precipitation for (a) 390 stations, (b) 5 stations near the Yucca Mountain site, and (c) 1 station (Beatty, Nevada).

this paper demonstrate that selected climate parameters important to the long-term performance assessment of the proposed MGDS at the Yucca Mountain site can be predicted. Although further work is necessary to validate the future climate forecasting capabilities of the RCM and GCM models, these preliminary results are a significant step toward predicting future climate conditions for the Yucca Mountain area.

ACKNOWLEDGEMENTS

The sample results presented in this paper are derived from the analysis performed by F. Giorgi, G. Bates, and S. Nieman of NCAR. This work is being performed under the auspices of the U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Project, under Contract DE-AC04-76DP00789.

REFERENCES

1. DOE (U.S. Department of Energy), "Site Characterization Plan for the Yucca Mountain Site," DOE/RW-0199, Washington, D.C. (1988).

2. GIORGI, F., and L.O. MEARNS, "Approaches to the simulation of regional climate change: A review." *Rev. Geophys.*, 29, 191-216 (1991).

3. DICKINSON, R.E., R.M. ERRICO, F. GIORGI, and G.T. BATES, "A regional climate model for the western U.S." *Climatic Change*, 15, 383-422 (1989).

4. GIORGI, F., "Simulation of regional climate using a limited area model nested in a general circulation model." *Journal of Climate*, 3, 941-963 (1990).

5. GIORGI, F., M.R. MARINUCCI, and G. VISCONTI, "Application of a limited area model nested in a general circulation model to regional climate simulation over Europe." *J. Geophys. Res.*, 95(18), 413-18 and 431 (1990).

6. ANTHES, R.A., E.Y. HSIE, and Y.H. KUO, "Description of the Penn State/NCAR Mesoscale Model Version 4 (MM4)." NCAR Technical Note, NCAR/TN-282+STR, 66 pp. (1987).

7. DEARDORFF, J.W., "Efficient prediction of ground surface temperature and moisture with inclusion of a layer of vegetation." *J. Geophys. Res.*, 83 pp. (1978).

8. ZHANG, D., and R.A. ANTHES, "A high-resolution model of the planetary boundary layer: sensitivity tests and comparison with SESAME-79 data." *J. Appl. Meteor*, 21, 1594-1609 (1982).

9. ANTHES, R.A., "A cumulus parameterization scheme utilizing a one-dimensional clout model." *Mon. Wea. Rev.*, 105, 270-286 (1977).

10. DICKINSON, R.E., P.J. KENNEDY, A. HENDERSON-SELLERS, and M. WILSON, "Biosphere-Atmosphere Transfer Scheme (BATS) for the NCAR Community Climate Model," NCAR Technical Note, NCAR/TN-275+STR, 33 pp. (1986).

11. KIEHL, J.T., R.J.WOLSKI, B.P. BRIEGLEB, and V. RAMANATHAN, "Documentation of Radiation and Cloud Routines in the NCAR Community Climate Model (CCM1)." NCAR Technical Note, NCAR/TN-288+IA, 109 pp. (1987).

12. SLINGO, J.M., "A cloud parameterization scheme derived from GATE data for use with a numerical model." *Q. J. R. Meteorol. Soc.*, 106, 341-362 (1980).

13. CROWLEY, T.J., and G.R. NORTH, "Modeling future climates for nuclear waste disposal." Proceedings: High Level Radioactive Waste Management, 1259-1266 (1990).

14. QUIROZ, R.S., "The climate of the "El Nino" Winter of 1982-83 - A season of extraordinary climatic anomalies." *Mon. Wea. Rev.*, 11, 1685-1706 (1983).

15. SHEA, D.J., K.E. TRENBERTH, and R.W. REYNOLDS, "A global monthly sea surface temperature climatology," NCAR Technical Note, NCAR/TN-345+STR, 167 pp. (1990).

16. TRENBERTH, K.E., and J.G. OLSON, "ECMWF Global Analyses 1979-1986: Circulation Statistics and Data Evaluation." NCAR Technical Note, NCAR/TN-300+STR, 94 pp. (1988).

END

DATE FILMED

3/25/92