CCM Progress Report—June 1993

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1. INTRODUCTION

The advantages of the Community Climate Model (CCM) concept, in which many scientists use the same basic model for a variety of scientific studies, were demonstrated in the CCM workshops held at NCAR in the summers of 1985, 1987 and 1990. The many diverse experiments and analyses presented at these workshops were complementary and led to much constructive dialog between experts in different disciplines. This interaction was particularly useful because all work was based on a common model. The Fourth Workshop on the CCM is being held 21 June–1 July 1993. Unfortunately, not all users of the CCM are able to participate in these workshops. To augment these workshops and to foster interchange between all users of the NCAR CCM, the CCM Advisory Committee recommended that a CCM Progress Report be prepared periodically for all users and potential users. The committee recommended that the bulk of this report consist of brief reports, which should be required of all CCM users, both inside and outside of NCAR. These individual reports are assembled in Section 4 of this report as submitted by the users with no additional editing.

Section 2 describes the current state of the CCM. The last CCM Progress Report (1990) summarized the expected components of CCM2 and the research which led to them. Development continued after that and the algorithms defining CCM2 were ultimately frozen in October 1991. During the following year, the code implementing these algorithms was optimized and documented. The model and control simulation history files were made available to the community in October 1992. This evolution is described in more detail in Section 2, along with details of the reports which document the model and its simulated climate. Since the model was frozen, research directed toward improvements of identified deficiencies in CCM2 has continued. Work underway in the Climate Modeling Section is also listed in Section 2. Other aspects are reported in individual reports.

Section 5 describes the fourth CCM workshop held in June 1993. This section includes a list of attendees and the meeting schedule.

At the recommendation of the Advisory Committee, the remaining sections of this progress report consist of cumulative lists of CCM-related theses and publications. These have been gleaned from the various individual reports submitted and are undoubtedly incomplete. Please inform the editor of errors and/or omissions so that future lists can be as complete as possible. The last section lists the CCM manuals which document the current and past supported versions of the CCM and its associated processor. Many of these, which were associated with older versions, are now out of print. The most recent versions should be used.
2. CURRENT STATE OF THE CCM

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Over the last three years Climate Modeling Section activities have focused on the final development of the recently released CCM2. This has involved the integration of a large number of disparate simulation capabilities, many of which were presented in their early form at the last CCM Workshop, into a single cohesive modeling framework. The individual and collective behavior of the various model components were validated against available observational data. These components were modified accordingly, followed by major refinements to the overall implementation for optimal computational performance.

The result of this effort, the NCAR CCM2, represents an entirely new atmospheric general circulation model for which most aspects of the formulation represent improvements over the CCM1. The principal algorithmic approaches carried forward from CCM1 are the use of a semi-implicit, leapfrog time integration scheme, the use of the spectral transform method for treating the dry dynamics, the use of a biharmonic horizontal diffusion operator, and the large-scale condensation process. In most other respects, the CCM2 makes use of new algorithms for both resolved dynamics and parameterized physics, all of which are documented in Hack et al. (1993), and briefly summarized here. The standard model configuration uses a horizontal spectral resolution of T42 (2.8 x 2.8 degree transform grid), 18 vertical levels, and a top at 2.917 mb. It employs a 20 minute time step by dynamically adjusting the spectral resolution of the top layer to maintain a Courant number of less than one.

Two major improvements are included in the CCM2 dynamical formalism. The first is the incorporation of a hybrid vertical coordinate which is terrain following near the surface (traditional sigma) and transitions to a pure pressure coordinate above about 100 mb. A second major change to the resolved dynamics is the incorporation of a shape-preserving semi-Lagrangian transport scheme (Williamson and Rasch, 1993) for advecting water vapor. This scheme can also be used to transport an arbitrary number of other scalar fields (e.g., cloud water variables, chemical constituents, etc.) as required by the application. The use of the semi-Lagrangian method largely addresses the many numerical problems exhibited by the spectral advection approach used in earlier versions of the CCM.

The cloud fraction parameterization in CCM2 is a generalization of Slingo (1987). Clouds can form in any tropospheric layer except the lowest model level, and cloud fraction depends on relative humidity, vertical motion, static stability and the convective precipitation rate. The cloud emissivities are determined from the local liquid water
The CCM2 treatment of longwave radiation remains much the same as in CCM1. The major change is the incorporation of a Voigt line shape to more accurately treat infrared radiative cooling in the stratosphere (Kiehl and Briegleb, 1991). The CCM2 also employs a δ-Eddington approximation to calculate solar absorption using 18 spectral intervals (Briegleb, 1992). To incorporate the effects of clouds, the scheme makes use of the cloud radiative parameterization of Slingo (1989), where the optical properties for liquid droplet cloud particles are parameterized in terms of the liquid water path and effective radius. Comparisons with available references suggest that the scheme accurately captures radiative heating from the surface through the mesosphere (≈ 75 km) with notable improvements in estimates of atmospheric absorption/heating below cloud decks. The δ-Eddington formulation also allows estimates of the photon flux necessary to compute photodissociation rates for chemistry applications, and provides a versatile way to incorporate the effects of aerosols.

A diurnal cycle is incorporated in CCM2, for which both solar and longwave heating rates are updated every model hour, while the longwave absorptivities and emissivities are updated every twelve hours. Land and sea ice surfaces are modeled as horizontally homogeneous media with vertically varying thermal properties. The subsurface temperatures are assumed to obey a thermal diffusion equation where the net energy flux at the surface/atmosphere interface is calculated using bulk exchange formulae in which the transfer coefficients are stability dependent.

A non-local boundary layer parameterization (Holtslag and Boville, 1993) is used in the NCAR CCM2 to represent turbulence in the atmospheric boundary layer (ABL). The parameterization scheme determines an eddy diffusivity profile based on a diagnosed boundary layer height and a turbulent velocity scale. It also incorporates non-local (vertical) transport by large eddies, thus providing a more comprehensive representation of the physics of boundary layer transport. Subgrid scale vertical transport of passive scalars by boundary layer turbulence is also treated.

Above the ABL, the local vertical diffusion scheme of CCM1 is retained, although the functional dependence of the diffusion coefficients is somewhat different. A parameterization of momentum flux divergence by stationary gravity waves is also included (McFarlane, 1987).

A simple stability-dependent mass flux scheme is used to represent all types of moist convection (Hack, 1993). The scheme utilizes a three-level conceptual cloud model that is applied to three contiguous CCM levels, starting from the bottom of the model and shifting up successively one level at a time, after which the column is stabilized. The convection parameterization makes use of temperature and moisture perturbations from the ABL parameterization to determine the initial thermodynamic properties of ascending parcels, and provides a consistent treatment of convective transports for an
arbitrary number of passive scalars. The initial release of CCM2 specified the land-
surface soil moisture. The Biosphere-Atmosphere Transfer Scheme (BATS) of Dickinson
*et al.* (1986) is now available as an option and is documented in Dickinson *et al.* (1993)
and Bonan (1993). As in CCM1, sea surface temperatures are specified by linear
interpolation between the climatological monthly mean values, but now use the data

Computationally, the model implementation has been reformulated, and rewritten
with several major objectives: compliance with the plug-compatible physics coding
standard defined by Kalnay *et al.* (1989); an improved user interface; and the
incorporation of highly optimized single-job vector multitasking capabilities. The
current implementation sustains approximately one half the theoretical peak floating
point performance of the NCAR Cray Y-MP/864, and exhibits parallel speedup
exceeding 7.2 in a dedicated environment. Several significant modeling capabilities have
been introduced in terms of history tape management, including a branch run capability
in which selected periods can be rerun exactly in order to obtain additional model
diagnostics (including higher temporal sampling). Modification of the basic model code
is also significantly easier than in previous versions of the CCM.

As before, a User's Guide (Bath *et al.* 1992) has been written to provide details of
the code logic, flow, style, and data structures, and to explain how to modify and run
CCM2. In contrast with CCM1, the code is internally documented, obviating the need
for a separate technical note describing each subroutine and common block in the model
library. Thus, the code itself, the User's Guide, and the description of the continuous
formulation and numerical algorithms (Hack *et al.* 1993), along with a series of reviewed
scientific publications, are designed to completely document CCM2. No reference to the
earlier technical reports documenting the CCM is required. A news directory has also
been established under the /ccm file system on the SCD Cray Y-MP/864 (and linked
to the cross-mounted file system /crestone/u1/ccm/news) for providing periodic and
timely updates on all aspects of CCM-related activities.

Two control integrations of the NCAR CCM2, a 20 year (case 388) and a 10 year
(case 414) experiment, have been made available to the user community on the NCAR
Mass Storage System (MSS). The control integrations are algorithmically identical,
however, the case 414 experiment is bit-for-bit reproducible using the final CCM2
program library source code. This has significant advantages for users who wish to
rerun portions of the control using the CCM2 branch run capability mentioned earlier
(and described in Bath *et al.* 1992).

Several other control simulations are also now available to the research community
including simulations at multiple horizontal resolution (R15, T21, T31, T63, and T106),
a ten year T42 simulation using the BATS land surface option, and a ten year T42
simulation using observed sea surface temperatures. Various statistical condensations
(e.g., monthly mean, variance, and time-filtered data) have been generated for all of the
available control integrations. A detailed description of these data sets is contained in Williamson (1993).

Aspects of the CCM2 dynamic, thermodynamic, and radiative climate statistics are documented in Climate Modeling Section (1993) and Kiehl et al. (1993). As discussed earlier, the physical representation of a wide range of key climate processes in CCM2 is much more physically realistic. The principal strengths of the simulated model climate are a significant reduction in the mean thermodynamic bias present in all previous versions of the NCAR CCM, and a significantly improved radiative balance. Nevertheless, there are a number of weaknesses in the simulated climate. The major problems include excessively warm summertime continental surface temperatures in the Northern Hemisphere, an anomalous positioning of deep convection in the Western Pacific which erroneously affects wave propagation and positioning in the January simulation, and an excessively cold polar tropopause. A solution to the warm continental surface temperatures, which involves improvements to the radiative properties of clouds, is already well along as described in the Progress Report section of this technical note. The poor positioning of January Western Pacific convection is under investigation and appears to be related to the interaction between moist convection and the atmospheric boundary layer scheme (which is excessively active with regard to water vapor transport in deep convective regimes). The cold polar tropopause, a characteristic feature of all atmospheric general circulation models, is also under investigation. Preliminary work suggests that this problem could be related to a deficiency in stratospheric momentum deposition by vertical propagating gravity waves (Boville, 1993).

Immediate plans are to continue to address these and other simulation deficiencies by improving the physical representation of the appropriate climate processes. Additionally, generalized capabilities for coupling CCM2 with other climate system components (e.g., ocean models, land surface models, etc.) will be explored and incorporated.

References (not included in sections 7 and 8)


3. ACKNOWLEDGMENTS

I would like to thank the many users of the CCM for responding to our request for their individual progress reports. Without such a complete response there would be no purpose in issuing this CCM Progress Report. I would also like to thank Ronna Bailey for her help in assembling all the components of this report and for producing the final camera-ready copy.
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I. Progress and Results

Some years ago we began a study to determine if an optimum model truncation existed which could be applied to an atmospheric prediction model in three dimensions and yield the best forecast for that truncation. We approached the study from a scaling perspective, looking for a three-dimensional scale index which would identify optimum truncation. It was apparent that scaling was available in spectral models using the eigenvalues of the expansion functions in the horizontal domain. However, no such indices existed in the vertical domain. Our first effort, therefore, was to identify optimum vertical structures for which indices existed. We chose those indices to be the equivalent depths of the vertical structure equations derived from the atmospheric perturbation equations based on a resting state. In order for the structures of the finite difference problem to coalesce with the theoretical eigenstructures, it was necessary to select the vertical levels in a special way. We tested levels chosen this way on the CCM0 and found significant sensitivity in the experiment; the results were reported by Baer and Ji (1989).

Subsequently, we sought a three-dimensional index which could be used as a truncation index by combining the horizontal spectral domain with the optimum vertical levels based on the eigenvectors as described above. We used the hypothesis of quasi-geostrophy to couple the horizontal with the vertical index. To establish the validity of this approach, we hypothesized that an error minimum should exist in model integrations if an optimum three-dimensional index were selected. This hypothesis was then tested on the CCM0, using only dynamics in the model to make the results more focussed. The statistics of many runs did indeed show that choosing a truncation based on a three-dimensional index with the proper relationship between the horizontal and vertical indices led to an error minimum in short-term forecasts (up to five days). Those results were presented by Ji and Baer (1992).

Finally, to test both the optimal vertical levels and the three-dimensional scaling in a more realistic model which also included forcing,
we ran a series of tests with the CCM1, comparing truncation of the model with its "standard" levels to a version with the "optimal" levels. Again the results, when compared to actual observations, indicated that the forecasts with the optimum levels appear closer to the observations. These results were presented by Baer and Zhu (1992). We are currently testing the NMC model under similar conditions on the presumption that since it is a state-of-the-art forecast model, results on forecast accuracy might be more definitive.

One of the outstanding observations of this entire endeavor is that more model levels than are currently used are needed in the stratosphere. This suggests that although the amplitude of the motion in the stratosphere is not sizeable, its structure acting nonlinearly has a significant impact on the atmosphere below it.

II. Students

(a) Ming Ji, Ph.D.
(b) Yu-Jian Zhu, M.S.
(c) William Campbell, Ph.D. candidate

III. CCM-Related Publications


The Biosphere-Atmosphere Transfer Scheme (BATS) Land Surface Option for the CCM2

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1. Progress and Results

The Biosphere-Atmosphere Transfer Scheme (BATS) has been implemented as an interactive land surface option in the CCM2. This model has been vectorized and the CCM2+BATS can be multi-tasked. Two ten year experiments with the coupled CCM2+BATS (one at T42 resolution, the other at R15) have been conducted.

2. Students and Thesis titles

none

3. CCM-Related Publications

none

4. Experiments and History Tapes

CCM2+BATS, T42, 10 years. This used new land surface data sets (vegetation, soil texture, soil color) derived for T42 resolution. The vegetation data set was derived from Olson's 0.5° by 0.5° data. The soil texture and soil color data sets were derived from Wilson's 1° by 1° data. These history tapes are not yet publicly available.

CCM2+BATS, R15, 10 years. The required land surface data sets were the same as those used in R15 CCM1+BATS research. These history tapes are not publicly available.
I. Progress and Results

A linear budget has been used to ascertain which of several proposed processes are most important in maintaining four prominent low-frequency perturbation patterns in a 6000–day perpetual January integration of CCM0B with fixed ocean temperatures. In the budget technique the time-average model equations are separated into those terms that are in common with the steady, adiabatic linearized form of the CCM and the remaining terms, which are treated as forcing terms. By examining the response of a linearized version of CCM0B to each of these forcing terms for prominent episodes of the low-frequency patterns, the terms that are most important in maintaining the low-frequency patterns have been determined. The results indicate that interactions between the low-frequency patterns and the time-mean zonal asymmetries of the model climate are crucial to the maintenance of the patterns. Of equal importance are anomalous fluxes transients, without which the low-frequency anomalies would not be maintained. Vorticity fluxes due to bandpass (1–7 days) fluctuations are found to be the most important components of the maintaining flux anomalies.

II. Students and Thesis Titles

None

III. CCM–Related Publications


IV. Experiments and History Volumes

CCM0B R15 perpetual January control (12 hourly data)

Days 0–1200: /CSM/X71001 to /X71081

Days 1200–6000: /LSD/L71081 to /L71401
I. Progress and Results

Analysis of the CCM1 simulation of the present-day Antarctic climate (Tzeng et al., 1993a) showed that the CCM1 has serious biases in simulating Antarctic climate, such as being too warm, having too much snowfall accumulation, and simulating too much cloud over the continent. The circumpolar trough is too weak and too far north. The major reasons for these biases are 1) the positive moisture fixer scheme, which artificially transports too much moisture into Antarctica, and 2) the low horizontal resolution, which distorts topography and hence the model simulations.

We also analyzed the Arctic climatology simulated by the CCM1 at R15 and T42 resolutions (Bromwich et al., 1992 and 1993), and found that the model pushes the North Atlantic storm track and the Icelandic Low to the west of Greenland instead of to the east of Greenland, as in the observations. This severely distorts the simulated exchange of energy in the North Atlantic sector between the midlatitudes and the Arctic Basin. This bias is primarily due to the amplified blocking effect of the broadened Greenland topography in the low (R15) horizontal resolution simulation. The CCM1 simulations at T42 resolution substantially alleviate this problem.

In addition, the CCM1(R15) can not simulate the prevailing Arctic stratus clouds in summer but oversimulates the low-level clouds in winter. This is due to the model simulations of moisture and low-level airflow (also sea-level pressure). Again, this bias results from the positive moisture scheme and the distorted topography.

The sensitivity of the CCM1 to a flat ice field at high southern latitudes in place of the elevated Antarctic ice sheets has been simulated for four model years. The results were compared with the CCM1(R15) control run data and with the mesoscale modeling results of Tom Parish. Two papers are expected to result, one on the low-level environment (Parish et al., 1993) and one on the circumpolar vortex.

Regarding the NCAR CCM2, we conducted a preliminary evaluation of the performance of this state-of-the-art GCM in comparison to the CCM1 and the ECMWF.
analyses. An extended abstract summarizing this analysis was prepared for the Fourth International Conference on Southern Hemisphere Meteorology and Oceanography (Tzeng et al., 1993b). The model's Antarctic climate was found to be much improved in comparison to the CCM1, particularly with regard to the surface winds, the circumpolar trough, the temperatures, the inversion strength, the double jet stream features, and the precipitation regime. The CCM2 can also well simulate each moisture budget component over the south polar cap area compared with the observations. This improvement is attributed to the semi-Lagrangian transport scheme. We anticipate submitting a manuscript for publication (Tzeng et al., 1993c) in the near future.

II. Students and Thesis Titles

None

III. CCM-Related Publications


IV. Experiments and History Tapes

4-year CCM1-R15 annual simulation with flat Antarctic topography, twice daily output (details available from R.-Y. Tzeng)
I. Progress and Results

The NCAR CCM1 with a R15 resolution has been used to examine the interannual and interdecadal variability of the climate systems and the blocking problems:

1. Examine the effect of the Pacific sea-surface temperature (SST) variation on the interdecadal variability of the winter atmospheric circulation in the North Pacific-North America region.
2. Examine the effect of the Pacific SST variation on the interannual variability of the summer atmospheric circulation.
3. Examine effects of three hypothesized (local, transient, and remote) forcings on the blocking of atmospheric circulation.

The NCAR CCM1 was used to perform two numerical experiments in which the SST Anomalies in the Pacific during the decades 1950-1959 and 1979-1988 [with respect to the 39-winter (1950-1988) mean SST] were imposed on the climatological SST of the NCAR CCM1 perpetual January central experiments. It was demonstrated that with the numerical simulation the observed interdecadal changes of the atmospheric circulation reported in this study were apparently associated with the interdecadal changes of the Pacific SST.

The NCAR CCM1 was used to perform a climate simulation with the real-time Pacific COADS SST for the period of 1975-1979. Significant interannual variations of the monsoon circulation and rainfall are generated by the climate experiment. For example, in the 1982 and 1987 summers, the model monsoon rainfall decreases and the model monsoon circulation including the tropical easterly jet and the Somali jet weakens, but this situation is reversed in the 1984 and 1988 summers. The interannual variation of the model monsoon circulation resembles the observed in many ways. Based upon various diagnostic analyses, it is concluded that the interannual variation of the Pacific SST is the sole boundary forcing generating the interannual variation of the model monsoon circulation in the climate simulation.

II. A linear transient nine-level primitive equation model has been developed to test three hypothesized mechanisms (local, transient, and remote forcing) by which blocking is initiated and maintained. The model simulations with all of these three forcings (the control run) show that the model can simulate both Pacific and Atlantic blocking in terms of spectral and energetics analyses, their time evolutions, and their spatial structures. By comparing different forcing experiments with the control run, we investigated the effect of the three forcings on the formation and maintenance of blocking. The results of these experiments indicate that the local forcing is the
primary forcing for the formation and maintenance of both Pacific and Atlantic blocking, although the mechanisms which cause blocking in these two regions are different. Pacific blocking is forced by the amplification of ultralong waves, either baroclinically or barotropically. However, Atlantic blocking occurs because of feedback effects between intense synoptic-scale waves and ultralong waves. Time-mean transient forcing is a minor forcing in the formation and maintenance of both Pacific and Atlantic blockings. The intensity and location of blocking are only slightly affected by transient forcing. Experiments with tropical (remote) forcing indicate that this forcing does not directly intensify the blocking flow, but rather amplifies the divergence circulations (and enhances the splitting of strong westerly flows) to provide a favorable environment for the formation of blocking.

III. Students and Thesis Titles
Ren-Yaw Tzeng (Ph.D) A Numerical Study of Blocking (1990)


Jau-Ming Chen (Ph.D) A Numerical Study of Interdecadal Variation in the Wintertime Atmospheric Circulation (1994 expected)

IV. Experiments and History Tapes
Sixteen-year (1975-1990) experiments with the real-time Pacific SST and the NCAR CCM1 (R15)
We have been investigating the sensitivity of the accuracy of 30-day mean forecasts by the CCM1 to initial and evolving weather regimes. The forecasts have been run by David Baumhefner from National Meteorological Center analyses during recent winter seasons (December through February, from 1978-79 to 1990-91). Forecast accuracy is measured by the area-averaged anomaly correlation between the forecast and analyzed 30-day mean 500 mb heights. The most accurate ensemble-mean forecasts over the Northern Hemisphere are, on average, associated with persistent, anomalously low zonal index initially over the western Atlantic Ocean. Conversely, the least accurate forecasts are, on average, associated with nonpersistent, anomalously high zonal index initially over the western Atlantic.

Over the Pacific Ocean quadrant of the Northern Hemisphere, the most (least) accurate CCM1 30-day mean forecasts are associated, on average, with anomalously low (high) initial zonal index over the western Pacific and with lower (higher) than normal western Pacific surface cyclone frequencies one month before forecast initialization. Furthermore, we have found that some of these least accurate forecasts are characterized by analyzed cyclone wave mergers over the central and eastern Pacific Ocean several days after forecast initialization. The wave mergers are followed in time by a downstream transition from anomalously low to anomalously high zonal index conditions, in some cases associated with the breakdown of blocking. In one case studied in detail, the wave merger and subsequent regime transition are not forecast by the CCM1 at medium range, hypothetically leading to an inaccurate 30-day mean forecast.

We are continuing to investigate the suggested relationships between weather regimes and CCM forecast accuracy.
PARTICIPATING GRADUATE STUDENTS

Wayne Bresky (M. S. program begun Fall 1992)
Thomas Hamill (Ph. D. program beginning Fall 1993)
Tianshi Li (Ph. D. research beginning summer 1993 on the impact of sea surface temperatures on CCM2 30-day mean forecast accuracy)
Yajiang Yang (M. S. research in progress on cyclone wave mergers and CCM1 30-day mean forecast accuracy)

CCM-RELATED PUBLICATION

Inclusion of Biosphere-Atmosphere Transfer Scheme (BATS)

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Patrick J. Kennedy
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I. Progress and Results

Over the past three years, work progressed in the BATS code and its linkage to CCM1. Connections to CCM2 are now finished and are the subject of another report by Gordon Bonan in this document. We were greatly assisted by an ever-growing group of BATS users, who use BATS as an offline one-dimensional program or connected to some overlying atmospheric model of various dimensions. Multi-year CCM1/BATS integrations brought to light several deficiencies that would not have been apparent in shorter runs; these deficiencies have been corrected. All our CCM1/BATS runs were at R15 resolution, and included a flux-corrected ocean with interactive sea ice. Investigation continues in carbon cycling and storage in the vegetation and soils.

The principal run was for 11 model years. A parallel run, also 11 years, has doubled CO2. Another parallel 3-year run has a deforested, degraded-soil Amazon Basin.

II. Students and Thesis Titles

None.

III. CCM-Related Publications


IV. Experiments and History Tapes

A. CCM1 with BATS1E, R15, half-hour time step, seasonal, flux-corrected ocean, interactive sea ice, Slingo radiation and cloud treatment, 1XCO2, 11-year run.

MassStore path: /KENNEDY/CCM1/224/WILLOW (6-90)

and /KENNEDY/CCM1/204/DILL (7-90)

B. Parallel run to above, but 2XCO2.

MassStore path: /KENNEDY/CCM1/125/YEW (6-90)

and /KENNEDY/CCM1/205/ELDER (7-90)

C. Parallel to last three years of the 1XCO2 run, but with deforested, degraded-soil Amazon Basin.

MassStore path: /KENNEDY/CCM1/206/FIG (8-90)

In all cases, daily output plus monthly averages are available in conventional history tape format; inquire of authors for usage.
ICE CLOUDS IN A GENERAL CIRCULATION MODEL

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I. Progress and Results

The 1990 CCM Progress Report described the experimental implementation of a parameterization for the water content of ice clouds in CCM1. Subsequently, several extensions of the parameterization have been developed: (1) The geometric thickness of ice clouds is implied by the assumptions used to infer the ice mixing ratio in the basic parameterization. In many cases, the clouds are thinner than the vertical resolution of CCM1. The parameterizations for geometric thickness and ice mixing ratio have been combined to parameterize the ice water path, which is directly required by many parameterizations for cloud radiative properties. (2) The aspects of the ice parameterization incorporated in CCM1 earlier dealt exclusively with the ice content in clouds which were saturated with respect to ice. Using observations obtained by A. Heymsfield for ice-crystal survival distances under various conditions of temperature and humidity, the ice water path in subsaturated layers below saturated ice clouds can be parameterized. A parameterization of this nature has been experimentally incorporated in CCM1. (3) The ice parameterization has been linked to CCM1’s thermodynamic and hydrological cycles. The ice parameterization does not assume that condensed water precipitates during the time step immediately following cloud formation but does allow for the vertical redistribution of water vapor as ice clouds form and dissipate. (4) The ice water paths from the parameterization can be used to calculate the solar albedo and longwave emissivities through CCM1’s radiative transfer code.

The ice-cloud parameterization has been tested by using analyzed global fields to predict the atmospheric ice distribution. The parameterized ice fields were used to infer visible optical depths and infrared emissivities, which were then compared with observations from ISCCP (International Satellite Cloud Climatology Project). This comparison, by B. Soden, has suggested that the parameterization performs reasonably in predicting monthly mean ice-cloud properties. Uncertainties in the size distribution of ice particles, which are required in addition to the ice water path to parameterize radiative properties, remain a key uncertainty.

II. Student

Brian J. Soden, The University of Chicago, Department of the Geophysical Sciences.

III. CCM-Related Publications


IV. Experiments and History Tapes

There are at present no history tapes of general interest associated with this project.
Application of a Cloud Microphysics Parameterization to the CCM

Steven J. Ghan
Battelle Pacific Northwest Laboratory
Richland, WA 99352

I. Progress and Results

A bulk cloud microphysics parameterization originally developed for cumulus cloud models has been adapted for application to stratiform clouds in GCMs. Approximations have been introduced to permit much longer time steps, and cloud droplet number has been introduced as a prognostic variable. Other prognostic variables are cloud water, cloud ice, and ice number, with rain and snow diagnosed from their respective balance equations. The parameterization has been applied to the NCAR CCM1, with temperature and water vapor replaced by condensation-conserved prognostic variables. The Rasch-Williamson semi-Lagrangian algorithm is used for the advection of water, ice, droplet number, and crystal number. The cloud water and cloud ice mixing ratios and number concentrations together determine cloud optical properties employed in a two-stream delta-Eddington solar radiation model. A cumulus parameterization scheme developed by Grell has replaced the moist adiabatic adjustment scheme.

II. Students

James McCaa, University of Washington

III. CCM-related Publications (since 1991)


IV. Experiments and History Tapes

Some time-mean history files are available at the National Energy Research Supercomputer Center.
CLIMATE SENSITIVITY
TO THE SPECIFICATION OF CLOUD RADIATIVE PROPERTIES
James J. Hack
Jeffrey T. Kiehl
National Center for Atmospheric Research
Boulder, CO 80307-3000

I. Progress and Results

Analysis of the CCM2 Northern Hemisphere summer circulation reveals a large warm bias, both at the surface and in the free atmosphere. Additionally, precipitation over the Northern Hemisphere continents is unrealistically large, in some areas by factors of two or more. Comparison with Earth Radiation Budget measurements also suggests significant deficiencies with regard to outgoing longwave radiation, absorbed solar radiation, and the associated cloud forcing estimates (see Kiehl et al., 1993). Since the simulated cloud fraction is in reasonable agreement with observational estimates, the conclusion is that the clouds are not behaving in a radiatively reasonable way. This suggests that the principal cause of the problems in the Northern Hemisphere summer circulation are related to deficiencies in the specification of cloud radiative properties.

The radiative parameterization of Slingo (1989) for liquid water droplet clouds is employed in estimates of cloud scattering and absorption in the CCM2 (see Hack et al., 1993). In this parameterization, the optical properties of the cloud droplets are represented in terms of the cloud liquid water path (LWP) and effective radius, $r_e = \int r^3 n(r) dr / \int r^2 n(r) dr$, where $n(r)$ is the cloud drop size distribution over radius $r$. Cloud liquid water paths (LWP) are computed from a prescribed, meridionally and height varying, but time independent, cloud liquid water density ($\rho_e$),

\[
\text{LWP} = \int \rho_e dz,
\]

where

\[
\rho_e = \rho_0 e^{-z/h_e},
\]

$\rho_0$ is equal to 0.18 g m$^{-3}$, and $h_e$ is a meridionally varying, empirically derived local liquid water scale height currently evaluated as

\[
h_e = A + B \cos^2 \phi,
\]

with $A = 1080$ and $B = 2000$. The cloud droplet effective radius is simply fixed at 10$\mu$m, which is appropriate for marine stratocumulus clouds (Slingo, 1989). We are currently exploring techniques in which the cloud droplet effective radius...
can be more realistically diagnosed as a function of space and time, and a
diagnostic approach in which cloud liquid water path is a function of the space
and time-dependent atmospheric state. Early indications are that a combination
of these two approaches substantially reduces the temperature and precipitation
biases observed in the CCM2 Northern Hemisphere summer circulation. Most
importantly, other aspects of the simulated climate appear to be unaffected (i.e.,
not degraded) by the additional degrees of freedom introduced with the new
cloud diagnostic formalism. We will continue to more thoroughly evaluate these
changes, as well as explore additional diagnostic capabilities (e.g., ice physics) for
the immediate future.

REFERENCES

Hack, J. J., B. A. Boville, B. P. Briegleb, J. T. Kiehl, P. J. Rasch, and D.
L. Williamson, 1993: Description of the NCAR Community Climate Model

budget of the NCAR CCM2 and Comparisons with the Earth Radiation Budget
Experiment (ERBE). Submitted to J. Geophys. Res.

Slingo, A., 1989: A GCM parameterization for the shortwave radiative properties

II. Students and Theses Titles
None.

III. CCM-Related Publications

Hack, J. J., 1993: Sensitivity of the simulated climate to liquid water path length

Kiehl, J. T., 1993: Sensitivity of the simulated climate to effective drop size

IV. Experiments and History Tapes

Contact the authors.
I. Progress and Results

As many radiatively and chemically important trace gases continue to increase in our atmosphere, the need to understand their sinks and sources is an important task. In our study, we address the issue of determining the net surface emissions of trace gases from large regions. We use the CCM2 Semi-Lagrangian transport model and compare the model tracer concentrations to observations and deduce the regional emissions using an inverse method based on the linear Kalman filter. Previously, it had been found by the authors that the Kalman filter can accurately and efficiently deduce regional surface emissions of trace gases by comparing a model to observations if the model transport represents the atmospheric transport exactly or nearly exactly. This pilot study was done in a low-resolution (R6) 3-D chemical transport model (Hartley and Prinn, JGR, 98, 5183-5198, 1993).

Currently, we are using the CCM2 at T42 resolution which is high enough resolution to simulate many of the high frequency events that are seen in the observations. Since, the model transport is based on calculated dynamics, many synoptic features although realistic in structure are of course not in phase with the observations. We have done exploratory inverse studies with the CCM2 and found that there are additional issues to address with a high-resolution model beyond those we found in the low-resolution model when implementing the Kalman filter. One of the main issues is the stronger seasonality in the transport that we find in the high-resolution model relative to the low resolution model. We are currently working on an improved approach developed using a simple analytical transport model and expect to have results soon that will address how well the available real-time observational networks (ALE/GAGE and NOAA/CMDL) can constrain the surface fluxes of species like CFCl3 from important source regions. We will also address the question of whether the transport calculated in the CCM2 can be used to determine sources or whether a transport model based on observed winds is necessary.
II. Students and Thesis Titles


III. CCM-Related Publications


IV. Experiments and History Tapes

Contact Author (Hartley@sea.mit.edu)
Diagnosis of Tracer Transport in the CCM2:  
Comparison of CFC-11 Simulation with Observations

Dana Hartley and Ron Prinn  
Massachusetts Institute of Technology, 54-1312  
Cambridge, MA 02139

and

Dave Williamson and Phil Rasch  
National Center for Atmospheric Research  
Boulder, CO 80307

I. Progress and Results

The latest version of NCAR's Community Climate Model (CCM2) contains a semi-Lagrangian tracer transport scheme for the purpose of advecting water vapor and for including chemistry in the climate model. In order to diagnose the CCM2 transport, we simulated CFCl₃ (CFC-11) in the CCM2 using industry based detailed source distributions and a photochemical sink and compared the model results to ALE/GAGE observations around the globe. We compared the model and observations on both 12-hour and monthly time scales. The higher frequency events allow us to diagnose the synoptic scale patterns in the CCM2 associated with the observational sites and determine uncertainties in our high resolution source distribution. We find that the CCM2 does simulate many of the key features, but there are still some seasonality differences needing further study.

II. Students and Thesis Titles


III. CCM-Related Publications


IV. Experiments and History Tapes

Contact Author (Hartley@sea.mit.edu)
Title: Vegetation Changes in a Greenhouse-Warmed World

Investigators:

A. Henderson-Sellers  
Climatic Impacts Centre, Macquarie University,  
Sydney, Australia

K. McGuffie  
Department of Applied Physics, University of Technology, Sydney,  
Australia

Progress:

A simplified Holdridge-type vegetation prediction scheme has been coupled to a version of the NCAR Community Climate Model (CCM1-Oz) which includes the Biosphere-Atmosphere Transfer Scheme (BATS) and a mixed-layer ocean. This interactive vegetation climate model has been used to conduct two complementary CO$_2$-doubling experiments: an instantaneous $2 \times$ CO$_2$ simulation (15 years in total) and a fast, transiently increasing CO$_2$ simulation (45 years in total). All existing model predictions of the likely climatic impact of doubling atmospheric CO$_2$ have assumed that the continental vegetation remains fixed, distributed as for present-day simulations. The only continental surface parameters which varied interactively have been the snow cover and soil moisture while other, equally important variables such as vegetation albedo and roughness length have been fixed at $1 \times$ CO$_2$ values even though it is well known that the specification of land-surface characteristics does affect the simulated climate. Here the sensitivity of the modelled climate to the inclusion of some aspects of an interactive biosphere is examined. There are some differences in the predicted vegetation distributions and areas. On the other hand, there is agreement that in a warmed world the vegetation type termed “agriculture” increases in area at the expense of deciduous needleleaf trees and short grass; and the tundra extent, already underestimated, decreases further while deserts and the deciduous broadleaf tree areas expand. Additional sensitivity tests have been conducted in $2 \times$ CO$_2$ conditions which were designed to try to establish: (i) the dependence of the resulting (equilibrium) predicted vegetation on the initialization and (ii) the confidence associated with the predictions of tropical forest areal extent. It was found that the extent of evergreen broadleaf tree (tropical forest) in doubled CO$_2$ climates is very little affected by disturbances including a prescribed replacement of the forest by scrub grassland and a different initialization of vegetation distribution. Similarly, the overall vegetation areas predicted are not particularly sensitive to initialization although its effects can be monitored for one to two years.
Publications:

Tropical vegetation and climate change, Fourth International Conference on Southern Hemisphere Meteorology and Oceanography, Hobart, 29 March – 2 April 1993


Climate system: continental surface processes, invited keynote presentation at the Aspen Global Change Institute’s Conference on “The Coupled Climate System and Global Change” (1–10 August, 1992)
Title: Global Climate Sensitivity to Tropical Deforestation

Investigators:
A. Henderson-Sellors, H. Zhang, T.B. Durbidge and A.J. Pitman
Climatic Impacts Centre, Macquarie University,
Sydney, Australia

K. McGuffie
Department of Applied Physics, University of Technology, Sydney,
Sydney, Australia

Progress:

Regional to global-scale climate sensitivity to tropical deforestation is being studied using a modified version of the NCAR Community Climate Model (CCM1-Oz) which includes a mixed-layer ocean model, a 3-layer sea-ice model and BATS (the Biosphere-Atmosphere Transfer Scheme). A fourteen-year control integration and a series of six year deforestation experiments in which the tropical moist forest throughout the Amazon Basin, S.E. Asia and tropical Africa is replaced by scrub grassland have been conducted. The three deforested regions sustain different impacts on their regional climates. The largest disturbances occur in the Amazon Basin where total precipitation decreases by \(-437 \text{ mm yr}^{-1}\), evaporation decreases by \(-231 \text{ mm yr}^{-1}\) and a marked decrease in moisture convergence is clear, although the surface temperature increases by 0.3K. In S.E. Asia, surface temperature decreases in 11 months with an annual average cooling of \(-0.7K\); total evaporation decreases all the year with 130 mm yr\(^{-1}\); while the sign of the precipitation changes is strongly seasonal. The African region is least affected by deforestation, although surface net radiation decreases year-round and there is a detectable decrease in moisture convergence in the dry season. Regional responses to deforestation differ because regional circulation patterns are affected differently. For example, while ground surface temperatures increase in the southern Amazon and over this basin as a whole, the northern Amazon, S.E. Asia and Africa all exhibit decreases in ground surface temperatures. The modification of atmospheric circulation patterns over deforested tropical regions prompts climate responses distant from the disturbance. Impacts of tropical deforestation include a disturbance of the Asian monsoon and small but statistically significant changes in climate in the middle and high latitudes.

Thesis: Zongliang Yang, PhD, 1992, *Improving soil hydrological parameterizations in atmospheric general circulation climate models*
Publications:


Modelling the hydrological response to largescale landuse change, Henderson-Sellers, A., McGuffie, K. and Durbidge, T.B., Procs. IHP (UNESCO)/IAHS Kovacs Symposium on “Space and Timescale Variability and Interdependencies in Various Hydrological Processes” (in press)


I. Progress and Results

Control and SST anomaly experiments have been performed using CCM1 at T31 resolution. The control consists of a 10-year seasonal simulation with climatological SSTs based on mean COADs SST data for 1950-79. Two anomaly experiments have been performed in which global SSTs evolve as observed for the periods 1981-November 1983 and July 1985-November 1987. Five independent realizations have been run for each 30-month period.

The atmospheric response of CCM1 for the 1985-87 El Niño cycle is studied in Hoerling et al. (1992). While little skill is found in simulating the response during the pre-El Niño 1985/86 winter, the simulations for the mature El Niño winter of 1986/87 are quite successful. An interesting feature of CCM1’s extratropical response over the Pacific/North American (PNA) region during the 1986/87 winter is a systematic eastward bias of the anomalous wavetrain centers compared to observations. A linear barotropic model is used to assess the impact of the CCM1’s climatological biases in altering its sensitivity to tropical forcing compared to that occurring in nature.

The dynamics of the wintertime atmospheric response to the 1986/87 El Niño in both CCM1 and nature is studied further in Ting and Hoerling (1993). Diagnostics with a linear baroclinic stationary wave model reveal that the 5 case ensemble mean CCM1 and observed wave train anomalies over the PNA region are maintained by different processes. For CCM1, the extratropical wave train is maintained almost equally by the effects of tropical diabatic forcing and transient vorticity fluxes. For observations, the transients are found to be the primary mechanism. A more comprehensive analysis of the origin of the extratropical response during El Niño is provided in Hoerling and Ting (1993). In that study, four recent observed El Niño winters are examined, the results of which are contrasted with those derived from the individual realizations of CCM1 simulations for the 1982/83 and 1986/87 El Niño winters. Results for model and observations are found to be quite different, and reasons for model failure are discussed.

II. Student and Thesis Related Titles: N/A

III. CCM Related Publications


I. Progress and Results

Several global satellite data sets have been processed and transformed into history tape format for use with the Community Climate Model (CCM) processor. Only a few of the most widely used and best documented data sets have been selected at this point, although future work will expand the number of data sets examined as well as update (when possible) the archived data. An attempt has been made to include data of longer record, so only monthly averaged data have been processed. Most of the data have been archived at both their original resolution and also transformed to a triangular wavenumber 42 (T42) truncation Gaussian grid for more direct comparison to CCM output.

The satellite data sets that have been archived in CCM history tape format include:

- Microwave Sounding Unit (MSU)
- International Satellite Cloud Climatology Project (ISCCP)
- Earth Radiation Budget Experiment (ERBE)
- Nimbus-7 Earth Radiation Budget (ERB)
- Nimbus-7 Cloud-Matrix (CMATRIX)
- Outgoing Longwave Radiation (OLR) Data from NOAA

These data sets are described in detail in Hurrell and Campbell (1992), where examples of how to access the data are given.

II. Students and thesis titles

None.

III. CCM-related publications


IV. History tapes

1. MSU brightness temperature data

This data set exists for January 1979 through December 1992. Monthly means exist for channels 2 (troposphere) and 4 (stratosphere), as well as for the lower tropospheric channel 2R. They are in /CTSAT/MSU/T42/CCM1H/7992T. To access 2.5° resolution data, simply change “T42” to “2.5DG” in the pathname.
A climatology for each month has been established based on the 10-year period 1982-1991, and those data are in /CTSAT/MSU/T42/SAVTAV/JAN8291T. Again, “T42” can be changed to “2.5DG”, and “JAN” can be changed to “FEB”, “MAR”, etc. to access the other monthly climatologies. Monthly mean anomaly temperatures have been created by removing the 10-year monthly means, and those data are in /CTSAT/MSU/T42/CCM1H/7992A for the T42 data.

2. ISCCP data

Stage C2 data from ISCCP have been archived from July 1983 through December 1990. Seventy-two fields have been archived. The data include monthly means for 00, 03, 06, 09, 12, 15, 18 and 21 UTC, as well as a complete monthly mean obtained by averaging the eight “hour-monthly” means. An example pathname is /CTSAT/ISCCP/T42/CCM1H/ALL/8307, which contains the complete monthly mean fields for July 1983 at T42 resolution. The 2.5° resolution data can be accessed by changing “T42” to “2.5DG” in the pathname. The hour-monthly mean data can be accessed by changing “ALL” to “00UTC”, “03UTC”, etc. in the pathnames.

A climatology for each month has been established from five archived years of ISCCP data. Only the complete monthly mean data have been averaged. An example climatology is /CTSAT/ISCCP/T42/SAVTAV/ALL/JAN8488 for January. July through December averages were constructed over the years 1983-87 (e.g., “JUL8387”), and the 2.5° data can be accessed by changing “T42” to “2.5DG”.

3. ERBE data

Of the many fields available from the ERBE S-4 data product, only those variables most similar to standard GCM derived fields have been archived. The monthly data are available from February 1985 through December 1989, and are contained in the directory /CTSAT/ERBE/T42/CCM1H/8589. To access 2.5° data, change “T42” to “2.5DG”.

Climatologies for each month have been produced from the data originally archived (February 1985–December 1988), so all averages except January were made over four years. An example pathname of a T42 resolution climatology is /CTSAT/ERBE/T42/SAVTAV/MAR8588 for March.

4. Nimbus-7 ERB and CMATRIX data

The Nimbus-7 spacecraft has produced several long term data sets of interest. Two have been archived for use with the CCM processor: Earth Radiation Budget (ERB) and Cloud-Matrix (CMATRIX). The data consist of monthly mean fields archived at 4.5° resolution. Only the most widely used fields from Nimbus–7 ERB have been archived for November 1978 through October 1987 on /CTSAT/N7ERB/4.5DG/CCM1H/7887.

Monthly ERB climatologies have been produced using data from 1981-1987, except for November and December (1981-1986). An example pathname is /CTSAT/N7ERB/4.5DG/SAVTAV/JAN8187 for January.

Many different fields have been archived for Nimbus–7 CMATRIX over the period April 1979 through March 1985. An example pathname is /CTSAT/N7CMATRIX/4.5DG/CCM1H/7904 for April 1979.

Climatologies for each month have been produced from the six years of CMATRIX data, so January through March averages include the years 1980–1985, while the other nine months include 1979–1984. An example pathname is /CTSAT/N7CMATRIX/4.5DG/SAVTAV/JAN8085 for January.

4. NOAA OLR data

This data set currently exists for June 1974 through December 1991 at T42 and 2.5° resolutions, although an update through December 1992 will be available soon. The data are stored in /CTSAT/NOAA/T42/CCM1H/7491, where “T42” can be replaced by “2.5DG”.

Climatologies for each month have been made using the data after 1978 so that 13 years have been averaged. An example pathname is /CTSAT/NOAA/T42/SAVTAV/JAN7991 for January at T42.
I. Progress and Results

This study has had two important goals:

A. [COHMAP/DOE]

Our co-PI Kutzbach and his group at the University of Wisconsin are responsible for using CCM to make actual simulations for selected times over the last 150,000 years, including application of the best available geologic reconstructions to use for boundary conditions and forcings. Our role at Brown (with the continued assistance of Oglesby who has subsequently moved to Purdue) is to perform sensitivity studies of these boundary conditions and forcings, with two main goals in mind: (i) help to assess the uncertainty in the model results based on the knowledge that the geologic reconstructions are not perfect, but are often subject to large uncertainties. (ii) These boundary conditions and forcings are really only fixed for specific points in time, but instead vary, often cyclically, themselves over relatively long time scales. Specifically, we have done the following:

1) 'Milankovitch' orbital insolation parameters. For her master's thesis, Hong Shao used the previous CCM0 simulations of Kutzbach at 0, 3, 6, 115, and 126 Kyr to compute formal linear sensitivity coefficients that on a gridpoint by gridpoint basis relate the response of important model variables (such as surface temperature and pressure) to the changes in forcing. She also computed as measures of the uncertainty the linear least squares misfit, a jackknife standard deviation, and the variability in a lengthy model control. The sensitivity coefficients, which can be normalized via a t-test, were then presented as geographic maps, with the further identification of regions that were similar in that they either had relatively high or low sensitivity. A journal paper reporting on these results is in the final stages of completion.

2) Ice sheet size and height. As a major portion of his PhD research Ben Felzer is performing a study that systematically varies ice sheet size and height over North America and Eurasia. To date, he has completed a series of perpetual season (January and July) simulations with CCM1 in which he set the area of the 21 kyr ice sheet (last glacial maximum) as '1', then varied this from 0.5 to 1.7 (i.e., an ice sheet with half the area to one with 1.7 times the area). He varied the height from 0 (background topography) systematically to almost 3 km. The first step was to attempt to perform a formal sensitivity analysis similar to what had been done by
Shao for orbital insolation changes (and Oglesby and Saltzman for CO$_2$ changes). This did not prove as meaningful as in these other studies as the analysis showed very large changes over and immediately adjacent to the ice sheets but surprisingly little change more than a few grid squares away from the ice sheets. These simulations did not however have an interactive surface hydrology or computed SST, either of which could serve to amplify the 'far-field' response to the ice sheets. In particular, analysis of the fluxes of sensible and latent heat over the Atlantic Ocean immediately off the coast of North America demonstrates large effects that could impact not only SST but also potentially aspects of ocean circulation as well. As research for a senior honor's thesis, undergrad Dena Hyman has made seasonal simulations with interactive hydrology and ice sheet height extremes. She continued to find little far-field effects. Next in line to make (starting this summer) are runs with a 'slab ocean' to compute SST.

B. [SPECMAP]

Modeling studies aimed at a better understanding of the climatic processes involved in the glacial-interglacial transitions of the late Pleistocene. To date, we have performed two different studies:

1) A study aimed at a better understanding of monsoon process and how to model these processes (Clemens and Oglesby 1992). This ability is important because the large Asian monsoon appears to have waxed and waned in conjunction with other Pleistocene climatic changes. We found that only when SST were computed did we get the right sequence of physical events and processes that couples the pressure anomalies over the Asian interior with circulation changes in the southern hemisphere Indian Ocean. When SST were prescribed, the end result over Asia was reasonably well-simulated, but the sequence of events was no longer well-simulated, suggesting an inability to properly predict changes in the monsoon under past or altered conditions.

2) A study aimed at understanding what effects changing sea ice distribution around Antarctica would have on the southern hemisphere atmospheric and oceanic circulation (Oglesby 1990 AGU abstract; Oglesby and Fan in prep). It has been speculated by Imbrie et al. that changes in this sea ice extent play a major role in the complex set of dynamical climate system processes that are responsible for the massive glacial-interglacial transitions of the late Pleistocene. We find that the magnitude of atmospheric and surface ocean circulations is roughly proportional to latitudinal sea ice extent, that is, the farther equatorward the sea ice limit, the stronger the circulations. We do not, however, find that the location, either in latitude or longitude, of circulation features does not change significantly, even when large longitudinal asymmetries are introduced in southern hemisphere sea ice.

II. Students


Benjamin Felzer, Ph.D in progress, Brown University, expected May 1995.
III. Bibliography


Felzer B., D. Hyman, R. J. Oglesby, H. Shao, T. Webb, W. Prell, and J. Kutzbach, in prep. The sensitivity of a GCM to systematic changes in orbital insolation. To be submitted to *J. Climate*.

Oglesby R. J. and Z. Fan, in prep. The influence of sea ice extent on the southern hemisphere atmospheric and surface ocean circulation. To be submitted to *JGR*.

IV. List of available history tapes

All history tapes are available on request. Since several dozen CCM1 runs are involved, it is not possible to specify the details here but contact B. Felzer for more information.
The Role of Differential Heating in Climate and Climate
Variability Within Simulations of the NCAR CCM

Donald R. Johnson
University of Wisconsin-Madison

I. Progress and Results

Research has focused on investigation of atmospheric heating, energy
exchange and the atmospheric component of the hydrologic cycle from climate
simulations of the CCM. The results of Hoerling et al. (1990) demonstrated
marked differences between heating distributions from perpetual January and
July simulations of CCMOB and CCM1. The current emphasis has been on
comparison of results from seasonal cycle simulations of CCM2 and CCM1. These
analyses are compared with corresponding climatological distributions and
distributions diagnosed from ECMWF datasets and Earth Radiation Experiment
(ERBE) data.

Major differences are found in distributions of atmospheric heating and
various components of the atmospheric hydrologic cycle between CCM1 and CCM2.
In both January and July, the heating within the primary tropical centers of
deep moist convection is substantially larger in CCM2 than CCM1. In both
January and July, the CCM2 heating in the monsoonal regions over Africa, the
Americas, Asia and the maritime continent is nearly double that in CCM1. In
January, the CCM2 tropical centers of heating are shifted southward of those
in CCM1.

In accord with the distributions of heating, the total precipitation in
CCM2 simulations is also markedly larger in tropical regions of deep
convection in both summer and winter seasons. In contrast, the large scale
component of precipitation decreases globally in CCM2 relative to CCM1, except
along the extratropical oceanic storm tracks of both hemispheres. The
increased total precipitation and the corresponding increased heating in CCM2
simulations results from greatly increased convective precipitation in CCM2
relative to CCM1.

Both January and July CCM2 simulations show sizeable increases in the
vertically integrated water vapor (precipitable water) over most of the globe
relative to CCM1. Locally, increases of 20 to 40% in precipitable water
content are present in CCM2 relative to CCM1 over the deep convective regions
in tropical latitudes. Large increases also occur locally in extratropical
latitudes, particularly in the Northern Hemisphere during July.

The comparisons for January and July indicate a much more intense
hydrologic cycle in CCM2 relative to CCM1. Similar statements are also valid
for the months of April and October. It is noted that the changes simulated
by CCM2 relative to CCM1 do not always result in better agreement with the
"observed" circulation.

II. Students and Thesis Titles: N/A

III. CCM related Publications:

from January and July Simulations of NCAR Community Climate Models. J.
Climate, 3, 417-434.

IV. Experiment and History Tapes: N/A
Tropical analysis of the horizontal divergence and moisture fields

Akira Kasahara and Arthur P. Mizzi
National Center for Atmospheric Research
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and

Leo J. Donner
Geophysical Fluid Dynamics Laboratory/NOAA
Princeton University, Princeton, NJ

I. Progress and results

To improve the quality of horizontal divergence and moisture analyses in the tropics, we are developing a tropical initialization procedure that will augment current diabatic nonlinear normal mode initialization (NNMI) schemes. This procedure performs initialization for cumulus convection by incorporating precipitation information obtained from satellite radiometric imagery data. This initialization scheme may be used as a method of quality control for first-guess fields in four-dimensional data assimilation. Since no daily analyses of precipitation are available, we have constructed the proxy data of daily tropical precipitation by developing a relationship between the pentad precipitation data of the Global Precipitation Climatology Project (GPCP) with daily outgoing longwave radiation (OLR) data.

The tropical belt from 35°S to 25°N (for January 1988) is divided into three parts: convective, convective fringe, and downward-motion (clear-air) areas. In the convective region, the algorithm adjusts the horizontal divergence and humidity fields such that a version of Kuo cumulus parameterization will yield the precipitation rates closest to the proxy data. The temperature in the planetary boundary layer is also adjusted, if necessary, to ensure the initiation of cumulus convection. In the downward-motion region, the divergence field is adjusted to yield descending motion expected from the thermodynamic balance between radiative cooling and adiabatic warming. In the convective fringe region, where convective criteria are not met, the divergence field is adjusted only to satisfy the global conservation of divergence. The humidity field is left intact in both the downward-motion and convective fringe regions.

This adjustment scheme is being tested as a diabatic initialization for cumulus convection to implement the application of NNMI for forecast experiments using a version of CCM1 with a Kuo cumulus parameterization. This adjustment scheme will ameliorate problems associated with the spinup of precipitation in a numerical prediction model with the same cumulus parameterization as used in the initialization.
II. Students and Thesis Titles

None.

III. CCM–related publications


IV. Experiments and history tapes

- CCM format input and history tapes
- Data source: ECMWF analyses
  - GPCP precipitation estimates
  - OLR data on 2.5° longitude–latitude grids
- Period: 1/1/88 1200 UTC as the initial time for CCM1 forecast
- Experiments: Many CCM1 forecasts for 42 timesteps (10.5 hrs) are run from various initial conditions with different combinations of the cumulus initialization and NNMI.
I. Progress and Results

We have studied the response of the CCM to changes in the seasonal and latitudinal distribution of solar radiation associated with orbital changes. Specific experiments were for 3, 6, 9, 12, 15, 18, 115 and 126 thousand years ago. We have used two different ice sheet heights for 18 thousand years ago to bracket the observational uncertainty. Many of these results will be published in a book describing COHMAP (Wright et al., 1993). We are currently using CCM 1, the version developed by S. Thompson and C. Covey that is coupled to a mixed-layer ocean. We have completed experiments for extremes of axial tilt and season of perihelion corresponding to "warm summer" and "cold summer" orbits to study the physical processes relating orbital change to climate change. We have completed a set of no mountain and half-mountain experiments with CCM 1 to test ideas on the role of uplift on climatic change over the past 5-10 million years. We have simulated the climate for the period around 250 million years ago when all the continents were joined to form Pangea. We have simulated the effect of orbital changes on Pangean climate.

II. Student and Thesis Titles


III. CCM-Related Publications (since July 1990)


IV. Experiments and History Tapes

All of the history tapes for experiments with CCM 0 for 3, 6, 9, 12, 15, 18, 115, and 126 thousand years ago, as well as the no mountain and half-mountain experiments are available to other users upon request. In addition our experiments with CCM 1 dealing with orbital changes, mountain uplift, and Pangean climates are available to other users upon request.
The basic concepts of land-sea temperature contrast and the strength of the Asian summer monsoon are investigated here by comparing the factors associated with producing this contrast in a number of atmospheric general circulation model simulations. All models are run with the same long-term mean sea-surface temperatures (SSTs) so that only land-surface conditions can affect the land-sea temperature contrast. The models include two versions of the National Center for Atmospheric Research (NCAR) Community Climate Model Version 0 (CCM0) (both run at R15, one with simple convective adjustment and the other with the Albrecht hybrid mass-flux convective scheme), the NCAR CCM1 at two resolutions (R15 and T42), and the Australian Bureau of Meteorology Research Centre R21 climate model. These models use a simple, bucket soil-moisture formulation with surface-air temperature equivalent to the temperature in the lowest model layer. There is a surprising consistency among the various models such that stronger summer monsoons (larger area-averaged precipitation over south Asia) are associated with greater land-sea temperature contrast, lower sea-level pressure over land, less snow cover, and greater soil moisture. Summer monsoon characteristics are examined in detail in the CCM0 and CCM1 and compared to a version of the CCM1 with the Biosphere-Atmosphere
Transfer Scheme (with a two-layer soil moisture calculation and surface air temperature computed at 1.5 m), and to the CCM0 version with convective adjustment and land albedos raised from 0.13 to 0.20. The various components of the hydrological cycle and surface energy balance are examined in these models for the winter-spring-summer sequence over the same area of southern Asia. There is a positive feedback between soil moisture–precipitation–cloud in the models (increased soil moisture provides a surface moisture source for further convection and precipitation), as well as a high sensitivity to the specified land albedos (lower land albedos are associated with warmer land temperatures, greater land–sea temperature contrast and a stronger Asian summer monsoon). The results suggest that the effects of land–surface conditions could be as strong as those of interannually varying SSTs for year-to-year changes in Asian summer monsoon intensity,

2. Progress and results during the last year:
Having already run the model in 1991 for four years with a methane tracer and methane photochemistry, I spent a bit of time updating my code to keep pace with model development. I ran a few shorter experiments, for example, testing the effect of an altered saturation vapor pressure profile on the formation of polar stratospheric clouds (PSCs), in order to understand and mitigate the effects of the excessively cold poles. I tested a higher-vertical resolution version (L75) of the CCM2 and ran the model for one year. At the AGU meeting last fall, my poster on the CCM2's stratospheric water vapor distribution featured a zonal mean cross-section for, fortuitously, roughly the same time period as Jim Russell's poster on HALOE water vapor data (from the Upper Atmosphere Research Satellite [UARS]), and they were astoundingly similar; out of this comparison grew a short paper (see below).

The chief results of the past year are that the model's lower stratospheric water vapor distribution is controlled by saturation processes, which are too strong in southern winter over Antarctica, and that relatively little air actually enters the stratosphere in the regions of the coldest tropical tropopause in the model. With higher vertical resolution, the dry region in the tropics seen in satellite data sets can be reproduced, but its presence has little effect on the lower stratospheric water vapor distribution in general.


5. Methane and clock (=age since parcel left boundary layer) tracers, resolution T31L35, CCM version plx13, with realistic middle atmospheric water vapor: /MOTEP/ccm2/T31mc2/hist/h037 through h074 is the fourth year of integration (day 360=Sept. 1). (Water vapor not quite in equilibrium.)

Methane only, T31L75, version plx17, annual cycle:
/MOTEP/ccm2/OWL75/hist/h0001
The purpose of SGCCP is to apply three-dimensional (3D) numerical models to study dynamical and transport processes in the stratosphere and mesosphere. Much of the planetary wave activity in the stratosphere is assumed to originate in the troposphere and to propagate vertically into the stratosphere. Instead of simulating the troposphere, we have adopted the mechanistic approach for a portion of our modeling efforts. Planetary wave information is introduced by forcing the lower boundary, or the reference surface, with analytic functions or with observed geopotentials. Our reference surface is isobaric and is continuously updated with NMC mandatory heights. An original nine-level CCMO was modified to accommodate stratospheric integrations with the mechanistic method. In addition, we substituted the algorithms of Rosenfield et al (1987) to generate heating and cooling rates. Ozone and water vapor were climatologically specified. Rayleigh friction approximated the momentum dissipation due to gravity wave breaking. Convective adjustment was retained, vertical diffusion was not, and the rhomboidal truncation was changed to triangular.

Time averaged mechanistic model horizontal winds have been interfaced with an offline 3D grid-point chemistry and transport model (CTM). Within the CTM, vertical winds are obtained kinematically to ensure continuity with respect to the transport numerics. The horizontal resolution of the CTM is close, and the vertical resolution is identical, to that of the mechanistic model. The constituent continuity equation is solved by process splitting, and each component of the advection is calculated prior, for active constituents, to the chemical production and loss. For offline transport studies, time averaged winds provide a more realistic description of the circulation over finite time intervals. The averaging interval is equal to the history file write interval, six hours.

Using mechanistic winds and temperatures, the CTM has been integrated for five months, beginning 1 Nov 1989, with a passive tracer, acting as a perturbed constituent, and with nitrous oxide, whose loss rates were derived from the GSFC two-dimensional chemistry model. The 3D experiment showed that the mechanistic model has a realistic residual mean circulation, and demonstrated the rapidity with which constituents can be transported in the mesosphere from one hemisphere to the other. We have been using the same winds to investigate the evolution of perturbed ozone, due to NOx chemistry, from solar proton events (SPEs). Following the Oct 1989 SPEs, ozone reductions persisted longer over the Arctic than over the Antarctic, even though the amount of NOx produced in each hemisphere should have been the same. Our simulations illustrate that the reason is related to the dynamics into which the perturbed chemistry was injected. In the southern hemisphere,
mixing of unperturbed air from low latitudes occurred with the final warming. In the northern hemisphere, the polar vortex was forming at the time of the SPE and large scale mixing of low-latitude air was inhibited. Photochemically perturbed air eventually filled the vortex.

Reference:

II. Students and thesis titles

None.

III. CCM related publications


IV. Experiments and history tapes

Contact the author.
I. Progress and Results

A. CCM1 Sensitivity to Atmospheric CO₂

Some of the most basic results of Oglesby and Saltzman (1990) were presented at the 1990 CCM Workshop, and described in the 1990 progress Report. Simulations were made with the following CO₂ values: 100, 200, 330, 460, 660, and 1000 ppm, with all simulations integrated for at least 15 seasonal cycles. A clearly nonlinear, logarithmic-like response in surface temperature was seen, with greater sensitivity for lower values of CO₂ than for higher values. Oglesby and Saltzman (1992) presented a formal sensitivity analysis for key climatic quantities, computing at every model gridpoint logarithmic sensitivity coefficients, and three measures of the uncertainty of these coefficients, the jackknife standard deviation, the least squares (log) misfit, and the ensemble standard deviation for the 20-year 330 ppm control. Variables were grouped into those that had a relatively large sensitivity to CO₂ changes (surface temperature, sea ice, and atmospheric specific humidity) and those that had a relatively smaller sensitivity (sea level pressure, winds, and precipitation).

More recently, we have made a simulation with a preindustrial (circa 1800 AD) atmospheric CO₂ level of 265 ppm. In Marshall et al. (in prep.) we compare these results with the 'present-day' (circa 1975) 330 ppm control, assessing both the overall model sensitivity as one increases CO₂ from 265 ppm to 330 ppm and the ability to detect this sensitivity above inherent model variability. We then compared these results to observed temperature variations from the 1850s until the 1980's, finding some correspondence both in magnitude and spatial patterns of change. For both model results and observations that the changes in climatic variables are more detectable in winter than in summer, despite the former being the time of greater variability.

B. CCM1 Sensitivity to Solar Luminosity Changes

The nature of the forcing to changes in (short wave)-solar luminosity is very different than that due to changes in CO₂ (long wave). Changes in solar luminosity are also of importance in studies of paleoclimate because this quantity has increased by about 30% since the inception of the solar system over 4 billion years ago. In Marshall et al.
We report the basic results for surface temperature for simulations with variations in the solar luminosity of -5%, -2%, 0%, +2%, and +5% relative to the present-day control value of 1370 Wm\(^{-2}\). Note that the 0% and 330 ppm 'controls' are equivalent, and that Marshall et al. (submitted) is analogous to that of Oglesby and Saltzman (1990) regarding CO\(_2\). We find a strongly linear sensitivity in surface temperature over land but a less-well defined linear sensitivity over ocean; indeed over ocean a log fit is as good (or as poor) as the linear fit.

A key goal of this study was to compare the model sensitivity to solar luminosity changes with that due to CO\(_2\) changes. Similarities or disparities could suggest the relative roles of the direct response to the forcing versus modulation by feedbacks. In Oglesby et al (in prep) we report on the computation of linear sensitivity coefficients for the solar luminosity simulations (as well as the same three measures of uncertainty as for CO\(_2\)) and then compare these results to those of Oglesby and Saltzman (1992). We find a marked similarity in the geographic patterns of sensitivity between solar luminosity and CO\(_2\); this, combined with the fact that the largest sensitivity to solar luminosity occurs in the high latitudes in winter, precisely when the forcing is smallest, suggest the importance of feedbacks, and that regions are either climatically-sensitive or 'climatically-insensitive'. This also has implications for the use of past warm earth climates as analogs for possible future climatic change and perhaps more importantly as important tools for model validation.

C. Very Long CCM1 Simulations

In order to better assess the statistical stationarity and low-frequency behavior of the CCM1, and hence to better evaluate the significance of the results described above, we have made three very long simulations with CCM1: (i) a 140 year run with 330 ppm CO\(_2\) and a prescribed climatological seasonal cycle of SST; (ii) a 140 year run with 330 ppm CO\(_2\) and SST computed via a slab ocean (Oglesby and Saltzman 1992); and (iii) an 80 year run with 460 ppm CO\(_2\) and computed SST. Though analysis of these runs is proceeding vigorously, due to the voluminous amount of output we do not yet have specific results or publications, except for aspects of the hydrologic cycle (see below).

D. Studies of the CCM1 Hydrologic Cycle

Zengquan Fan, MS Candidate under Oglesby at Purdue has made a study of the regional variability of the hydrologic cycle (atmospheric and surface) over 100 years of the 330 ppm computed SST run described under C); the regions he studied were North China and eastern North America in summer. He found that the variability over eastern North America could be explained in terms of slight shifts in mid-continent summertime ridge in association with variabilities in soil moisture and Gulf of Mexico moisture transport, but that the North China variability was more complex, and related to subtle shifts in circulation features of the Pacific Ocean, South China Sea, and Asian continental interior.

Most recently, we have begun a collaboration with John Roads, Scripps Institution of Oceanography, on a study aimed at detailed analysis of the global hydrological cycle in CCM1, using both the very long simulations to estimate low frequency variability, and the suite of CO\(_2\) simulations, to see how the hydrologic cycle varies as a function of CO\(_2\). Preliminary results will be presented at the workshop by Roads et al.
II. Students

Zengquan Fan (MS in progress) Purdue University, expected August 1993

Michael Mann (PhD in progress) Yale University, expected May 1994

III. Bibliography


Marshall S., R. J. Oglesby, and B. Saltzman, Sensitivity of the equilibrium surface temperature of a GCM to systematic changes in solar luminosity. submitted to *Geophysical Research Letters*.

Marshall S., M. Mann, R. J. Oglesby, and B. Saltzman, A comparison of the CCM1-simulated climates for pre-industrial and present-day CO2 levels. In preparation; to be submitted to special MECCA issue of *Global and Planetary Change*.


IV. List of available history tapes

All history tapes are available on request. Since several dozen CCM1 runs are involved, it is not possible to specify the details here but contact R. Oglesby for more information.
I. Progress and Results

A. Mechanisms of glaciation

In this section we update results from the 1988 and 1990 CCM Progress Reports pertaining to questions of Antarctic and northern hemisphere glaciation.

Antarctic glaciation:
In the previous reports we discussed basic modeling efforts regarding Antarctic glaciation (Oglesby 1989) and for glacial conditions when Australia is joined to Antarctica (Oglesby 1991). Briefly, to first order the polar position and topographic height of Antarctica are most important in accounting for the presence of the massive ice sheet; SST, CO₂ and continentality (joining Australia to Antarctica) are of lesser importance. More recently, we have used CCM1 to investigate very large and very small Pliocene (3-5 million years ago) Antarctic ice sheet configurations. We found that the small ice sheet configuration was 'stable' and could by inference be maintained, but that the large ice sheet configuration was unstable and the model results suggest that by inference it could not be maintained.

Northern hemisphere glaciation:
In the 1990 Progress Report, we reported on an initial study (Oglesby 1990) aimed at the determination of northern hemisphere 'glaciation sensitive' regions. We imposed 1 meter (water equivalent) of snow cover over all northern hemisphere land points, finding that the model tended to maintain (and increase) this snow cover over northern Canada, Alaska, the Tibetan Plateau, and much of central and eastern Siberia. Little sensitivity was seen to changes in SST but a larger sensitivity occurred with changes in CO₂. More recently, in conjunction with M. Verbitsky, (Verbitsky and Oglesby 1992) we have expanded this study to include use of a dynamical ice sheet model. In this study, we imposed 10 meters of water equivalent snow cover initially over all northern hemisphere land points, and then determined the net annual snow mass balance for input into the ice sheet model. We had to increase the initial snow depth from 1 m to 10 m in order to have year-round snow cover for at least one year in regions with net snow melt (i.e., a negative mass balance). The same geographic regions as were 'glaciation sensitive' in the previous study tended to grow ice sheets. When we determined the sensitivity of total ice volume to CO₂ variations
from 100 ppm to 1000 ppm, we found a linear decrease in ice volume with increasing CO$_2$; furthermore we found that the magnitudes involved were an order of magnitude less than those of the ice sheets at the Last Glacial Maximum (21,000 years ago). However, as noted below, the magnitudes of the model results may be suspect.

B. Model improvements in snow hydrology

Of paramount importance to the study of glaciation and crucial to any study of long-term climate is the ability to accurately and precisely model the seasonal cycle of snow cover. This computation is, however, very crudely done in most current GCMs, including CCM1. As a step towards correcting this deficiency, we have incorporated the physically-based snow hydrology of Marshall (1989) into CCM1 (Marshall and Oglesby 1993). This new parameterization includes the effects of snow age, grain size, and fractional snow cover on the albedo of a snow-covered surface. We found that the seasonal cycle of snow cover in a present-day control was improved with use of the new snow hydrology; in particular the spring-time melt was simulated much more realistically. We expect that because of its more physically-realistic formulation use of the new snow hydrology will also improve the predictive capability of the model when applied to questions of past climates or possible future climatic change. As a test of this we repeated select Antarctic simulations of Prentice et al. (1993) and northern hemisphere simulations of Verbitsky and Oglesby (1992). Very little impact was seen on the basic results for Antarctica but a profound difference was seen in the results for the northern hemisphere. In this latter case, use of the new snow hydrology does not change the overall functional rate of ice volume decrease with increasing CO$_2$ but the resultant ice sheets in every case are much larger, and for low values of CO$_2$ may approach the total volume of ice at the Last Glacial Maximum.

C. Gulf of Mexico update

The original suites of Gulf of Mexico experiments (Oglesby et al. 1989; Maasch and Oglesby 1990) have been augmented by a series involving a crude eastern hemisphere analog of the Gulf of Mexico, the South China Sea (Oglesby and Maasch, presented at the 1991 INQUA Meeting, Beijing China). Briefly, cooling the Gulf of Mexico with otherwise present-day conditions results in a diminishment of the North Atlantic storm track in winter, and in summer drier conditions over the eastern two-thirds of the United States but with an enhanced monsoonal flow in to the southwest. When Gulf of Mexico coolings are imposed on other boundary conditions for 12,000 years ago (12 ka), these same types of effects are seen; in winter they tend to offset the other 12 ka boundary conditions but in summer they tend to augment them. Cooling the South China Sea produces many of the same kinds of effects though generally not as large in magnitude. Interestingly, larger effects are seen over the Atlantic than over the Pacific, suggesting perhaps a greater sensitivity for the former region.

II. Students


Taipeng Zhang (PhD, in progress) Yale University; expected May 1994

Haijun Hu (PhD, in progress) Yale University expected May 1994
III. Bibliography


Oglesby, R. J., 1990: Sensitivity of glaciation to initial snowcover, CO₂, snow albedo, and oceanic roughness in the NCAR CCM. Climate Dynamics, 4, 219-235.


Oglesby, R. J., 1991: Joining Australia to Antarctica: GCM implications for the Cenozoic record of Antarctic glaciation. Climate Dynamics, 6, 13-22.


IV. List of available history tapes

All history tapes are available on request. Since several dozen CCM1 runs are involved, it is not possible to specify the details here but contact R. Oglesby for more information.
THE EFFECT OF ORBITAL INSOLATION CHANGES ON CRETACEOUS CLIMATE AND CYCLIC SEDIMENTATION

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I. Progress and Results

We have made a large number of perpetual January and July simulations using CCM1 and geographic and SST reconstructions for the middle and the late Cretaceous. We made simulations varying the combined effect of precession and eccentricity systematically while holding obliquity fixed; simulations varying obliquity while holding precession constant, and simulations systematically varying both parameters. In our original work (Oglesby and Park 1989; Park and Oglesby 1990; 1991 much of which was reported on in the 1990 Progress Report) we made this suite of simulations for the mid Cretaceous (about 100 million years ago). We have subsequently repeated many of these simulations for the late Cretaceous (about 70 million years ago) (Park and Oglesby 1993). A critical difference between the two sets of simulations is the treatment of SST. For the 100 Ma simulations we used SST derived from previous GCM simulations using a swamp ocean. For the 70 Ma simulations we used SST based on the geologic reconstructions of Horrell (pers. commun.).

We find large, systematic changes in the Cretaceous climate, especially in monsoonal circulations, as the effect of precession is systematically changed. We find that in general the effect of obliquity is small compared to that of precession at all latitudes, but that the effects of obliquity are nonetheless surprisingly important at low latitudes. Rigorous statistical analysis combining all the model results says that the response of model variables to orbital insolation changes cannot, given inherent model variability, be distinguished from a purely linear response. The response of the hydrologic cycle to insolation changes is consistent with several scenarios of Cretaceous cyclical bedding in the Tethys Sea and South Atlantic Ocean.

We find that the mean climatic state for the late Cretaceous is very different than that for the mid Cretaceous, although the paleogeographic reconstructions differ more in detail than in large-scale feature. The differences are particularly striking in the atmospheric hydrologic cycles. We attribute the main cause of the different climates to be the different SST. In particular, the mid and low latitude meridional gradients are much less in the 70 Ma SST reconstructed from geology than in the 100 Ma SST obtained from a previous CCM0 study. Clearly related to this, the response of the 70 Ma climate to orbital insolation changes, though generally of the same sense, are subdued relative to those at 100 Ma.

II. Students

None
III. Bibliography:


IV. List of available history tapes

All history tapes are available on request. Since several CCM runs are involved, it is not possible to specify the details here but contact R. Oglesby for more information.
Response of Zonal Winds and Atmospheric Angular Momentum to a Doubling of CO₂

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I. Progress and Results

The possible impact of doubling CO₂ on zonal mean zonal winds and the angular momentum of the atmosphere was examined using general circulation model output archived by the Goddard Institute for Space Studies, the Geophysical Fluid Dynamics Laboratory, and the National Center for Atmospheric Research (the version of CCM0 described by Washington and Meehl, 1984). Whereas the emphasis in many previous model studies has been placed on the surface temperature and precipitation changes expected from a doubled-CO₂ scenario, the intent here was to investigate some of the dynamical consequences predicted by these models, especially within the tropics where the zonal wind and temperature changes are less tightly coupled than elsewhere.

Comparisons among the three models of the difference in zonal mean zonal winds between 2 x CO₂ and 1 x CO₂ simulations indicate a common tendency when CO₂ is doubled for winds to become more easterly in much of the tropics during June-July-August. Less of a consensus for the tropics emerges for December-January-February, perhaps as a result of differences among the models' basic climatologies for the zonal wind field. In general, however, changes predicted for the zonal winds in the tropics, and elsewhere, are comparable to the interannual variability currently observed, suggesting that these changes ought to become detectable eventually.

Largely because of the tropical wind changes, decreases in the troposphere's relative angular momentum accompany a doubling of CO₂ in all the model runs. The amplitude of the decrease in the NCAR simulation is 40% of the model's seasonal cycle in angular momentum, a sizeable response. Although this result suggests that an anthropogenic effect on Earth's rate of rotation is possible, such a prediction must be regarded as tentative in light of the shortcomings found in the models' zonal wind climatologies and the differences among their zonal mean responses.

II. Students and Thesis Titles: N/A

III. CCM-Related Publications


IV. Experiments and History Tapes: N/A
AFRICAN REGIONAL CLIMATE: CCMn-MM4 NESTED SYSTEM SIMULATIONS

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I. Progress and Results

The Sahelian region of the African continent has experienced a persistent trend of decreasing rainfall during a large part of this century. This study is based on a high-resolution CCM1/MM4 nested model climate simulation system which employs realistic representation of the vegetation over Northern Africa to investigate the sensitivity of the Sahelian climate to large scale SST anomalies.

Two northern hemisphere summer (June, July, August) experiments were performed using the CCM1/MM4 nested system: the first case corresponds to the 1950 SST anomalies when the Sahelian region was relatively wetter than the long-term average and the second case corresponds to the 1984 SST anomalies which was one of the driest rainy seasons experienced in the last few decades. For each of the cases, the CCM1 simulation starts from the same initial conditions where the orbital parameters required for computing the solar zenith angle are set to values for October 15 and is integrated for a total of 15 months. The CCM1/MM4 nested system is then starts from the last 2 weeks of May and until the end of August, since this is the rainy season for the Sahel region. The first two weeks of the integration are ignored since they represent model spin-up time.

Figure 1 shows the CCM1 total rainfall accumulation difference between the 1984 and 1950 SST anomaly simulations during the June, July and August months of the integrations. This figure depicts a broad region of negative rainfall anomalies across much of Western Africa with the exception of the coastal regions which is consistent with the observed conditions between the wetter climate of 1950 compared with the severe drought of 1984. The CCM1/MM4 nested system provides a greater detailed structure in the rainfall field compared to the CCM1 simulations alone. The rainfall maxima in the nested system has shifted toward the west coast thus exhibiting a more realistic rainfall distribution pattern. Figure 2 shows the CCM1/MM4 rainfall difference field, 1984 minus 1950, and the general reduction of rainfall in 1984 compared to 1950 is apparent over most of the region except along the coast of West Africa which has anomalies of the opposite sign. Although CCM1 correctly simulates the general reduction in rainfall for 1984 compared to 1950, the CCM1/MM4 nested system yields more realistic and detailed regional climate due to its inclusion of more detailed effects of topography, land-sea contrast and land surface processes.
II. Students and Thesis Titles

Beverly Burns (M.S.)  

Cary Gentry (M.S.)  

III. CCM Related Publications:


IV. Experiments and History Tapes

None.

Fig. 1 Difference (1984-1950) for ninety-day accumulated precipitation for Jun-Jul-Aug for CCM1. Units in cm and contour intervals of 5 cm.

Fig. 2 Difference (1984-1950) for ninety-day accumulated precipitation for Jun-Jul-Aug for MM4. Dash lines are negative contour intervals.
I. Progress and Results

This investigation uses CCM1 to examine the role of global sea surface temperature (SST) anomalies in the modulation of the climate of Africa. The focus of this work is the climate anomaly pattern phase reversal which was characterized in the 1950s with abundant rainfall over tropical Africa, including the Sahel region, and below normal rainfall over the equatorial region. This pattern dramatically reversed in the 1970s when drought conditions prevailed over most of Africa except in the equatorial region which experienced above normal rainfall.

Two separate CCM1/R15 ten year simulations were performed. In the first case the global SST distribution in CCM1 for each calendar month was set to the corresponding monthly 1950 ("wet year") SST conditions while the second case employed the 1973 ("dry year") SST conditions. These particular years correspond to two extreme Sahelian climate anomaly polarities during the decades of the 1950s and 1970s.

Analysis of the ten-year seasonal and annual model output averaged fields have been compared with observational data to assess the role of SST in the continental scale teleconnection that existed during the 1950s and 1970s. The analysis indicates that CCM1 successfully simulates the prominent features of the annual mean climate conditions over Africa and the seasonal migration of the rainfall belt. Of more importance, the observed teleconnection climate anomaly pattern under investigation and its decadal time-scale phase reversal are evident in the model simulations. Figures 1 and 2 show model averaged ten-year precipitation for the 1950 (months of Sept-Oct-Nov) and the difference (1973 - 1950) for the same months, respectively. The figures exhibit the model’s ability to reproduce the primary climate regimes over Africa.

The model output of the two simulations is currently being prepared for use in conjunction with a barotropic linear model to further examine the African continental climate.

II. Students and Thesis Titles

Beverly Burns (M.S.)  

III. CCM Related Publications:


IV. Experiments and History Tapes

Two CCM1/R15, ten-year runs have been completed. History tapes for:
"wet year" case /SEMAZZI/006/H006001-H006250
"dry year" case /SEMAZZI/010/H001001-H0010250.

Fig. 1 CCM1 ten year seasonal precipitation average for 1950 SON. Units in mm/season and intervals of 100mm.

Fig. 2 CCM1 ten year seasonal precipitation difference for 1973-1950 SON. Contour intervals of 50 mm.
I. Progress and Results

A series of model experiments have been made with NCAR CCM1/R15 to study the sensitivity of the model climate to moisture transport by cumulus clouds. The Albrecht et al. (1986) hybrid convective parameterization has been incorporated into the NCAR CCM1, and installed on a CRAY/XMP216 at the Research Information Processing Station (RIPS) of the Agency of Industrial Science and Technology, Tsukuba, Japan.

The hybrid cumulus parameterization produces a more realistic simulation of the vertical transport of moisture than does the moist adiabatic adjustment procedure employed in the standard model. The climate simulations using the hybrid scheme have upper-tropospheric temperatures in the tropics that are significantly greater (by about 3.5 °C) than those obtained with the standard model. Additionally, middle tropospheric mixing ratios of water vapor are greater (by approximately 2 g/Kg) than what is produced in the standard model. Although these differences are large, the hybrid temperature and moisture simulations are much closer to observed conditions than simulations produced by the standard CCM1.

A problem that arises when using hybrid convective parameterization is that the simulated cloud coverage in the tropics is much greater than observed. The increased coverage is the result of enhanced subgrid-scale vertical transport of water vapor in the tropics. Consequently, outgoing longwave radiation (OLR) is about 40 W/m^2 smaller than what is obtained with the standard model, and what is observed by the Earth Radiation Budget Experiment (ERBE). This problem with the top-of-atmosphere radiation budget can be corrected by modifying the CCM1 cloud scheme, which was originally tuned for the colder/dryer climate produced by the standard model. The modification incorporates a scale factor on the predicted cloud amount which is a function of pressure. This modification was applied for a perpetual January and July integration, and results in more reasonable estimates of cloud cover along with an improved top-of-atmosphere radiative balance.
REFERENCES


II. Students and Theses Titles

None.

III. CCM-Related Publications


IV. Experiments and History Tapes

Contact the authors.
OBSERVATIONAL DATA FOR CCM VALIDATION

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I. Progress and Results

This project uses global analyses from the European Centre for Medium Range Weather Forecasts (ECMWF) and the U.S. National Meteorological Center (NMC) reformatted into T42 truncation CCM history tape format for use with the CCM Processor. Time series of four times-daily or twice-daily analyses exist for both centers along with monthly mean statistics and long-term mean climatologies. At present these are on pressure surfaces, but in the future some archives will also exist on sigma (NMC) and hybrid (ECMWF) levels. Fields from CCM model runs can be processed in much the same way as the analyzed data.

The details of the ECMWF analyses and how to access them are published in an atlas (Trenberth, 1992).

II. Students and thesis titles

None.

III. CCM-related publications


IV. History tapes

The full description of history tapes for the various ECMWF datasets, monthly means, and climatologies is given in Trenberth (1992).
1. T106 spectral EC data at 14 levels 4 times per day.
   This dataset is now updated January 1985 through December 1992. The data are uninitialized. They are in /TRENBERT/CTEC with names ET42yymmDD, where yy is year, mm is month, and DD is day and is 01,04,07,10,13,16,19,22,25,28 and sometimes 31 for months with 31 days.
   The monthly and longer term means are in /TRENBERT/CTEC/TAV/ET42yymmM and the long term means /TRENBERT/CTEC/TAV/ET42mmM8589 (for 1985 to 1989) or 8689 (for 1986 to 1989).

2. 2.5° gridded EC data at 14 levels 2 times per day.
   This exists from January 1985 to January 1992. This is a derivative of the above but was received on a 2.5° grid. The data are uninitialized and twice daily. It is on a T42 grid in directory /TRENBERT/CTGAN/U with names ET42yymmDD, where yy is year, mm is month, and DD is day and is 01,06,11,16,21,26 and sometimes 31 for months with 31 days.
   The /U is to distinguish these analyses from other initialized analyses on the CTGAN directory, as documented in TN 373 (and see 3. below). Monthly means and long-term means follow the naming convention above but are in directory /TRENBERT/CTGAN/U/TAV

3. 2.5° gridded EC data at 7 levels 2 times per day.
   This exists from December 1978 through December 1989, with December 1979 missing. The data are initialized. It is on R15 and T42 grids in directory /TRENBERT/CTGAN with names ER15yymmA, ER15yymmB, for R15 and ET42yymmA or ET42yymmB for T42, where yy is year, mm is month, and the A and B refer to the first half (days 1 to 15) or second half of the month.
   Monthly means exist for all months and many different climatologies exist for differing periods in the directory /TRENBERT/CTGAN/TAV and with form ER15yymmM or ET42yymmM where the M is literal (for mean) for monthly means or ET42mmMy1y2 for the climatology for month mm from y1 to y2 (e.g., ET4201M7988 for the January climatology from 1979 through 1988).

4. 2.5° gridded NMC data at 12 levels 2 times per day.
   Data are archived at T42 for January 1987 - December 1991. Missing NMC analyses have been replaced with ECMWF analyses to complete the archive. Originally archived virtual temperatures have been replaced with temperatures. All are in the directory /TRENBERT/CTNMC and the names are similar to those for EC CTGAN in 3. above. i.e. /TRENBERT/CTNMC/NT42yymmA for days 01-15 and NT42yymmB for days 16-28,29,30 or 31.
   Monthly means are in /TRENBERT/CTNMC/TAV. The dataset name is NT42yymmM, where NT42 is literal, yy is the year, mm is the month, and M is literal.

5. Time-filtered EC data for 2 to 8 day periods
   5.1: December 1978 through December 1989, with December 1979 missing. From the dataset 3. above. All datasets are in the directory /TRENBERT/CTGAN/TAVF archived at T42 with monthly mean dataset names ET42yymmF, where ET42 is literal, yy is the year, mm is the month, and F is literal, and climatologies ET42mmMy1y2F where y1 is 78 or 79 (beginning year) and y2 is 87 or 89 (last year).
   See Trenberth (1991b) for a full description.

   5.2: January 1985 - January 1992. From dataset 2. above. All datasets are in the directory /TRENBERT/CTGAN/U/TAVF at T42 with name ET42yymmM, where ET42 is literal, yy is the year, mm is the month, and M is literal.
A SEMI-LAGRANGIAN VERSION OF CCM2
David L. Williamson and Jerry G. Olson
National Center for Atmospheric Research
Boulder, CO 80307-3000

I. Progress and Results

A semi-Lagrangian version of the NCAR Community Climate Model (CCM2) has been developed. Special consideration has been given to energy consistency aspects. In particular, approximations were developed in which the pressure gradient in the momentum equations is consistent with the energy conversion term in the thermodynamic equation. In addition, consistency between the discrete continuity equation and the vertical velocity $\omega$ in the energy conversion term of the thermodynamic equation was obtained.

Simulated states from multiple year simulations from the semi-Lagrangian version and the original Eulerian CCM2 have been compared. The principal difference in the simulated climate appears in the zonal average temperature. The semi-Lagrangian simulation is colder than the Eulerian at and above the tropical tropopause. The terms producing the thermodynamic balance have been examined. It is argued that the semi-Lagrangian scheme produces less computational smoothing of the temperature at the tropopause than the first order finite difference vertical advection approximations in the Eulerian version. Thus, by decreasing this particular computational error, the semi-Lagrangian produces less computational warming at the tropical tropopause. The net result is a colder tropical tropopause.

II. Students and Theses Titles

None.

III. CCM-Related Publications


IV. Experiments and History Tapes

All simulations examined in the paper above are available for additional analysis. Please contact the author for details.
5. FOURTH WORKSHOP ON CCM

The Fourth Workshop on CCM is being held 21 June–2 July 1993. As before, the workshop consists of two parts. The first week consists of tutorials and offers hands-on experience to a limited number of participants in running the model and processor; the second week of the two-part program is devoted to scientific presentations and discussions and is open to a wider audience. All users of the CCM are encouraged to participate in the second week of the workshop.

Advanced graduate students and recent graduates accepted to participate in the first week of tutorial sessions are:

Ms. Brenda Alcorn  Department of Meteorology  University of Utah
Ms. Beverly Burns  Dept. of Marine, Earth and Atmospheric Sciences  North Carolina State University
Mr. Thomas Chase  Department of Atmospheric Science  Colorado State University
Mr. Minghang Chen  Institute for Terrestrial and Planetary Atmospheres  State University of New York, Stony Brook
Mr. Jiun-Dar Chern  Department of Earth and Atmospheric Sciences  Purdue University
Mr. Benjamin Felzer  Department of Geological Sciences  Brown University
Dr. Andrea Hahmann  Institute of Atmospheric Physics  University of Arizona
Mr. Haijun Hu  Department of Geology and Geophysics  Yale University
Mr. Yong Xiang Hu  Geophysical Institute  University of Alaska, Fairbanks
Mr. Tianshi Li  Department of Soil, Crop, & Atmospheric Sciences  Cornell University
Mr. Nicholas Mangus  Department of Atmospheric Sciences  University of Illinois, Champaign-Urbana
Mr. Jerrold Robaidek  Department of Meteorology  University of Maryland
The list of participants for the second week of the workshop in addition to the above listed students follows:

<table>
<thead>
<tr>
<th>Name</th>
<th>Department/Section</th>
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<tbody>
<tr>
<td>Dr. Ferdinand Baer</td>
<td>Department of Meteorology</td>
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<td>University of Maryland</td>
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<td>Mr. Gary Bates</td>
<td>Interdisciplinary Climate Systems Section</td>
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<td>Ms. Linda Bath</td>
<td>Core Group/Climate Modeling Section</td>
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<tr>
<td>Mr. Thomas Bettge</td>
<td>Climate Sensitivity and CO₂ Research</td>
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<td>Mr. Michael Bosilovich</td>
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<td>Dr. Andreas Bott</td>
<td>Institute for Physics of the Atmosphere</td>
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<td>Johannes Gutenberg University, Mainz</td>
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<td>Dr. Byron Boville</td>
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<td>Dr. Kenneth Bowman</td>
<td>Department of Meteorology</td>
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<td>Texas A &amp; M University</td>
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<td>Dr. Esther Brady</td>
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<td>The Byrd Polar Research Center</td>
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<td>Dr. Lawrence Buja</td>
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<td>Dr. Phillip Chen</td>
<td>Fujitsu America</td>
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<td>San José, CA</td>
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<td>Name</td>
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<tr>
<td>Dr. Tsing-Chang Chen</td>
<td>Climatology &amp; Meteorology Program, Iowa State University</td>
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<td>Dr. Robert Chervin</td>
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<td>Dr. Hung-Neng Chin</td>
<td>Lawrence Livermore National Laboratory, University of California, Livermore</td>
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<td>Dr. Julianna Chow</td>
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<td>Dr. Steven J. Cox</td>
<td>Atmospheric Sciences Research Center, SUNY, Albany</td>
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<td>Dr. Robert Dickinson</td>
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<td>Dr. Leo Donner</td>
<td>Geophysical Fluid Dynamics Laboratory, Princeton University</td>
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<td>Mr. Brian Eaton</td>
<td>Climate Modeling Section, CGD/NCAR</td>
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<td>Dr. Jay Famiglietti</td>
<td>Climate System Modeling Program, UCAR</td>
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<td>Mr. Mark Gibbs</td>
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<th>Name</th>
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<td>Dr. Michael Prather</td>
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<td>University of Maryland</td>
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Dr. Yi Zang
Atmospheric Sciences Research Center
SUNY, Albany

Dr. Minghua Zhang
Institute for Terrestrial & Planetary Atmospheres
SUNY, Stony Brook
Monday, June 28, 1993

8:00 – 8:45 • Registration (outside Main Seminar Room)

8:45 – 8:55 • Welcome/Introduction: W. Washington and D. Williamson (NCAR)

Session Chair: W. Washington

8:55 – 9:05 • Overview of the CCM2: J. Hack (NCAR)

9:05 – 9:30 • J. Kiehl (NCAR): Simulated earth radiation budget in the CCM2

9:30 – 9:55 • J. Hack (NCAR): Parameterization of moist convection in the CCM2

9:55 – 10:20 • G. Bonan (NCAR): Land surface climatology of the NCAR CCM2 at R15 and T42 resolutions

10:20 – 10:50 • BREAK

10:50 – 11:15 • D. Williamson (NCAR): CCM2 simulations using observed sea surface temperatures and at different horizontal resolutions

11:15 – 11:40 • J. Hack and J. Kiehl: Climate sensitivity to the specification of cloud optical properties

11:40 – 12:05 • J. Hurrell (NCAR): An evaluation of three atmospheric general circulation models

12:05 – 1:30 • LUNCH

Session Chair: D. Williamson

1:30 – 1:55 • M. Zhang (SUNY), J. Hack, J. Kiehl, and R. Cess: A diagnostic approach for understanding climate feedbacks in atmospheric general circulation models

1:55 – 2:20 • F. Baer (University of Maryland): Long wave radiation algorithms in global climate modeling
Monday, June 28 (cont.)

2:20 – 2:45 • R. Tzeng, D. Bromwich (Ohio State University), and T. Parish (University of Wyoming): Validation of the NCAR CCM2 simulations over both polar regions

2:45 – 3:15 • BREAK

3:15 – 3:40 • K. Holcomb, F. Bryan, and W. Holland (NCAR): Coupling the CCM2 to ocean models

3:40 – 4:05 • R. Dickinson, (University of Arizona), P. Kennedy, and G. Bonan (NCAR): Land simulation in CCM2 with BATS

4:05 – 4:30 • A. Mizzi and A. Kasahara (NCAR): Comparison of daily tropical precipitation from CCM1 and CCM2 with satellite estimates of observed precipitation

4:30 – 4:55 • K. Bowman (Texas A&M): Design and analysis of numerical experiments

5:00 • RECEPTION NCAR Cafeteria Patio

Tuesday, June 29, 1993

Session Chair: P. Rasch

9:00 – 9:25 • A. Lenzen, T. Schaack, and D. Johnson (University of Wisconsin): A comparison of the hydrological cycles in CCM1 and CCM2

9:25 – 9:50 • J. Roads (UCSD), S. Marshall (University of North Carolina), and R. Oglesby (Purdue): Large-scale aspects of the NCAR CCM1 hydrology

9:50 – 10:15 • S. Marshall (University of North Carolina) and R. Oglesby (Purdue): An improved snow hydrology for GCMs, Part I: Snow albedo and snow cover fraction

10:15 – 10:45 • BREAK

10:45 – 11:10 • G. Meehl (NCAR): Intercomparison of CCM Asian monsoon simulations

11:10 – 11:35 • T.-C. Chen and N. Yen (Iowa State University): Interannual variation of the Indian monsoon simulated by the NCAR CCM: Effect of the western tropical Pacific SST

11:35 – 12:00 • G. Rao and K. Tepecik (St. Louis University): Organization of monsoon convection as simulated in the NCAR CCM, as observed through satellite imagery and depicted by an analytical model

12:00 – 1:30 LUNCH
Tuesday, June 29 (cont.)

Session Chair: J. Hack

1:30 – 1:55 • B. Burns, F. Semazzi, N.-H. Lin (North Carolina State University), and J.-K. Schemm (General Science Corporation): A GCM study of the sensitivity of African continental climate to global sea surface temperature anomalies

1:55 – 2:20 • F. Semazzi, N.-H. Lin, B. Burns (North Carolina State University), and F. Giorgi (NCAR): A CCM1-MM4 nested model study of the sensitivity of Sahelian climate to anomalies in sea surface temperature

2:20 – 2:45 • G. Branstator (NCAR): Forcing of the global atmosphere by equatorial heating

2:45 – 3:15 • BREAK

3:15 – 3:40 • B. Boville (NCAR): Atmospheric boundary layer parameterization in the CCM2

3:40 – 4:05 • Y. Zhang, W.-C. Wang, and M. Dudek (SUNY): Cyclone frequency simulated from CCM1

4:05 – 4:30 • B. Otto-Bliesner (University of Texas): Effects of tropical mountains and glacial ice on the climate over tropical land

4:30 – 4:55 • T. Glancy (Maritime Consultants): CCM0A sensitivity studies of Milankovitch scale insolation variations on the paleoclimate of the cretaceous western interior seaway

Wednesday, June 30, 1993

Session Chair: J. Kiehl

9:00 – 9:25 • D. Hartley, R. Prinn (MIT), D. Williamson, and P. Rasch (NCAR): Diagnosis of tracer transport in the CCM2: Comparison of CFC13 simulations with ALE/GAGE observations

9:25 – 9:50 • B. Boville (NCAR): Middle atmosphere version of CCM2: Annual cycle and interannual variability

9:50 – 10:15 • M. Takahashi, (University of Tokyo): A QBO-like oscillation in a two-dimensional GCM

10:15 – 10:45 • BREAK
Wednesday, June 30 (cont.)

10:45 – 11:10 • P. Rasch (NCAR): Chemistry and transport in the CCM2

11:10 – 11:35 • P. Mote (University of Washington): Using a stratospheric version of the CCM2 to study methane and stratospheric water vapor

11:35 – 12:00 • G. Stenchikov, A. Robock, Y. Liu (University of Maryland), and K. Taylor (LLNL): Modeling of El Chichon eruption cloud induced atmospheric reaction

12:00 – 1:30 • LUNCH

Session Chair: G. Bonan


1:55 – 2:20 • T.-S. Li and S. Colucci (Cornell): The relationship between atmospheric circulation regimes and numerical 30-day mean forecast accuracy over the north Pacific Ocean

2:20 – 2:45 • A. Kasahara and A. Mizzi (NCAR) and L. Donner (GFDL): Diabatic initialization of cumulus convection for CCM as a global forecasting model

2:45 – 3:15 • BREAK

3:15 – 3:40 • W. Washington and T. Bettge (NCAR): Progress on a new coupled model for greenhouse-sensitivity studies with 1° world ocean and dynamic sea-ice components

3:40 – 4:05 • R. Oglesby (Purdue), S. Marshall (University of North Carolina), and B. Saltzman (Yale): A comparison of GCM sensitivity for CO_2 and solar luminosity changes

4:05 – 4:30 • S. Cox, W.-C. Wang (SUNY), and S. Schwartz (Brookhaven): Modeling the regional and seasonal response to increased anthropogenic sulfate aerosol


5:00 • PICNIC NCAR Mesa Tree Plaza
Thursday, July 1, 1993

Session Chair: B. Boville

8:00 – 8:25 • S. Taguchi (National Institute for Resources and Environment, Japan) and J. Hack (NCAR): The climate of the CCM1 with a hybrid cumulus convection

8:25 – 8:50 • S. Ghan (Battelle Pacific Northwest Laboratory) and J. McCaa (University of Washington): Application of a cloud microphysics parameterization to the CCM

8:50 – 9:15 • L. Donner (GFDL): Ice clouds in the CCM

9:15 – 9:45 • BREAK

9:45 – 11:00 • DISCUSSION / End of Meeting
6. CUMULATIVE LIST
OF CCM-RELATED THESES


**Theses in Progress:**


7. CUMULATIVE LIST
OF CCM-RELATED PUBLICATIONS


Erickson, D. J., and R. J. Oglesby, 1993: Climate response of general circulation models to changes in cloud albedo. submitted.


Iwasaki, T., 1989: A diagnostic formulation for wave-mean flow interactions and Lagrangian-
mean circulation with a hybrid vertical coordinate of pressure and isentropes. J. Meteor.

Ji, M., and F. Baer, 1992: Three-dimensional scaling and consistent truncation of global atmos-


Kiehl, J. T., 1991: Modelling and validation of clouds and radiation in the NCAR Community Climate Model. ECMWF/WCRP Workshop Proceedings: Clouds, radiative trans-
fer and the hydrological cycle., ECMWF, Reading, U.K., 413–450.


1817.


Ramanathan, V., and E. J. Pitcher, 1982: Linking NCAR radiation routines with GCMs and its application to CCM0. Documentation for the Community Climate Model (CCM), Version 0, Climate Section, National Center for Atmospheric Research, Boulder, Colo., NTIS PB82-194192.


8. LIST OF CCM MANUALS

CCM0A


CCM0B


CCM1


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CCM2


Initial Data


Processor


Validation Data Sets


Workshop and Progress Reports


