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FINAL REPORT
Research on the Climatic Effects of
Nuclear Winter

Robert E. Dickinson

Submitted by

National Center for Atmospheric Research
Boulder, Colorado

Contract No. SF 12206

SANL 408-001

December 3, 1986

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FINAL REPORT

Research on the Climatic Effects of Nuclear Winter*

Robert E. Dickinson

OVERVIEW

Since beginning work on this contract in early 1984, the National Center for Atmospheric Research (NCAR) has undertaken a series of research efforts to develop and implement improvements to the Community Climate Model (CCM) needed to make the model more applicable to studies of the climatic effects of nuclear war. These studies were done, in most cases, to augment and complement ongoing NCAR research activities.

As of this date, the development of the model improvements has reached a stage where implementation may proceed, and several of the developed routines are now being incorporated into the next approved version of the CCM (CCM1). Formal documentation is now being completed describing the specific model improvements that have been successfully implemented.

This final report includes as attachments the series of annual proposals and progress reports that have guided the project. Formal documentation of the activities and accomplishments is presented in the series of reports listed in the attached set of publications.

* This work was prepared under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract W-7405-Eng-48.

ATTACHMENTS

1. SANL 306-011 and overall work statement, dated May 21, 1984.
2. NCAR Proposal 84-4.1, dated July 1984
3. Letter progress report for FY84 from R.E. Dickinson, dated Sept. 7, 1984.
4. Letter progress report for FY-85 from R.E. Dickinson, dated March 21, 1985
5. NCAR Proposal 84-4.2, dated August 1985
6. Letter progress report clarifying NCAR Proposal 84-4.2 from R.E. Dickinson, dated October 25, 1985.
7. Letter progress report for FY-86 from R.E. Dickinson, dated May 2, 1986
8. Letter final report from R.E. Dickinson, dated December 3, 1986.
9. List of publications and reports.

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ITEM NO.	DESCRIPTION	QUANTITY
	<p>This SAHL is issued to the National Science Foundation (NSF) to support the work which will be conducted for LLNL by the National Center for Atmospheric Research (NCAR) under DOE Interagency Agreement No. DE-A103-84SF12208.</p> <p>An Interagency Agreement has been established for this work. The work performed by NCAR will be for development on and application and acquisition of the Community Climate Model. This model is to be improved in ways that will permit both institutions to use the model as part of their research programs into the global-scale atmospheric effects of nuclear exchange and other programmatic studies as described in the "Work Statement".</p> <p>The LLNL cost estimate on the above work is \$50,000.00 for FY84. The total LLNL cost estimate on the above work is \$650,000.00; however, only \$50,000.00 is being released at this time. The remaining \$600,000.00 will be released for work to be done in FY85 and FY86. The period of performance will be for the period ending September 30, 1986. The work is being funded by the Atmospheric and Geophysical Sciences Division.</p> <p>NSF Contacts: Aaron Asrael and Ilene Buie. NCAR Administrative Contact: David Waltman NCAR Technical Contact: Stephen Schneider</p> <p>The agreement was placed with: National Science Foundation Attn: Contracts and Grants Aaron Asrael/Ilene Buie 1900 G St., N.W., Room 644 Washington, D.C. 20550</p>	

/CONTINUED ON PAGE 2/

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ITEM NO	DESCRIPTION	QUANTITY
	The nature of the work is such that only NCAR can provide this service. Requestor is responsible to notify the Special Materials Office when work is complete. Upon notification of completion, the Special Materials Office will request that all funds be accrued in the current fiscal year.

Authorized By

Peter E. Wise
UNIVERSITY OF CALIFORNIA

WORK STATEMENT

LLNL and NCAR herewith undertake to improve the Community Climate Model (CCM) in ways that will permit both institutions to use the model as part of their research programs into the global-scale atmospheric effects of a nuclear exchange and other programmatic studies.

Model Development to be Undertaken by NCAR

CCM studies of the global effects of a nuclear exchange have indicated a number of areas requiring improvements to the model if an accurate physical representation of important processes is to be achieved. These areas include:

1. Radiative transfer. The radiative transfer package presently in the CCM does not allow for incorporation of scattering aerosols such as nuclear war generated smoke or dust. It is proposed to develop a new radiative transfer capability for use in nuclear war/climate studies and other important aerosol/climate problems (e.g., volcanic dust, cloud droplets). A primary goal would be to incorporate a highly modular package having much improved flexibility for all types of atmospheric radiative transfer problems and the capability of easy modification. The programs would be tested in one-dimensional models before inclusion in the general circulation model. It is anticipated that this work would take 2 to 3 years.
2. Planetary boundary layer and surface processes. The calculation of transients in surface temperature is crucially important in general circulation model studies of the nuclear war/climate problem. The present CCM includes only a crude zero heat capacity land surface and no explicit planetary boundary layer (PBL) parameterization. The importance of the correct simulation of low-level cloud and/or radiation fog formation to the surface temperature transients must be studied using more detailed parameterizations than are presently incorporated. A combination PBL parameterization and improved surface physics package must be included in the CCM before the detailed time and space evolution of surface temperature can be reasonably trusted. The improvements would be tested with the diurnal solar cycle. Work would take about 2 years.
3. Sub-grid scale vertical convection. Nuclear smoke will be transported vertically by convection as well as by large scale motions, especially in the intensely heated upper regions of smoke clouds. The sub-grid scale parameterization of convection used in the CCM is a simple convective adjustment, which does not allow for movement of any quantity other than moist static energy. An improved convective parameterization that explicitly includes vertical mass and moisture flux must be specifically included in order to simulate the vertical movement of smoke. Work would take about 2 years.

4. Tracer transport and removal. The three-dimensional advection and removal of smoke and dust must be included in any comprehensive simulation of the nuclear war/climate problem. At present there is no capability in the CCM of doing this. An improved horizontal advection scheme for high-gradient tracers is needed because the present advection in spectral space is known to have serious deficiencies. Moreover, the transformation, coagulation, sedimentation and scavenging of aerosols is a difficult microphysical problem that will no doubt require successive generations of parameterizations of increasing refinement. Little is known about how a three-dimensional GCM will react to a strongly radiatively active patchy tracer substance. For this reason crude preliminary tracer simulations should also be performed, perhaps using the present spectral formulation, in order to develop intuition about model behavior and to attempt to uncover any model problems that may need attention before detailed tracer studies can be performed. Since LLNL is developing a tracer model that can be synchronously coupled to the CCM, support from this contract will be mainly to assure that a comparison can be made with the internally calculated CCM tracer transport capability to be developed separately by NCAR.

LLNL funding would be combined with NCAR and other funding to provide for personnel and necessary computer resources for model improvements in each of these areas. Emphasis in model improvement would be as follows:

FY-84: Task 2
FY-85: Tasks 1, 2, 3
FY-86: Tasks 1, 3, 4

Transfer of Improved Subroutines to LLNL

LLNL will provide the resources necessary to transfer the version of the CCM to be used by NCAR in these studies to the LLNL computer system. The version of the CCM to be transferred and associated processing routines are currently available from NCAR (and possibly other sources) and transfer to LLNL is expected to begin in the spring of 1984.

Model application studies will be conducted by both LLNL and NCAR as part of their respective programs. As part of this contract, NCAR will provide available documentation and magnetic tape copies of the improved subroutines for use in the CCM upon completion of initial testing of the subroutines. Adaptation of the codes to the LLNL computer system will be the responsibility of LLNL personnel, with NCAR to provide advice in response to specific inquiries.

Model Application Studies with the CCM at LLNL

Use of the CCM to investigate the consequences of a nuclear exchange will be undertaken by both LLNL and NCAR as part of their own programs. This contract does not restrict either organization in any way from conducting such model studies.

In addition, joint model studies may be provided for under this contract by the LLNL technical contact and the NCAR co-principal investigators, particularly when CCM model improvements made as part of this contract are first used in verification and application studies.

Other Contract Provisions to be Included

1. All model improvements made by NCAR under this contract shall be freely available to both NCAR and LLNL for use in other models available at their institutions.
2. All work done under this contract will be unclassified.
3. All model improvements and developments and all joint application studies may be published by either institution, subject to (1) normal internal scientific peer review procedures of the institution(s) of the author(s); (2) official patent, classification, and contract review procedures.
4. For joint model studies done at LLNL, LLNL will provide computer time and office support for visiting NCAR personnel. For visits of LLNL staff to NCAR, NCAR will provide office support.

Contract Term and Expected Approximate Funding Level

The contract is to cover the period FY-84 to FY-86, with each extension beyond the first year subject to annual re-approval by each institution. From preliminary discussions funding is estimated as follows; an official cost breakdown to be submitted by NCAR.

	FY-84	FY-85	FY-86
Personnel (incl overhead)	25	215	185
Consultants/Travel	5	5	5
NCAR Computer Time	<u>20</u>	<u>80</u>	<u>110</u>
Total	50	300	300

Project Objectives by Year

- FY-84: Selection of improved PBL/surface parameterization.
Initiate transfer of CCM and associated input/output codes to LLNL computer system.
- FY-85: Implementation and testing of improved PBL/surface parameterization.
Development of new radiative transfer package for CCM.
Development of new convective prescription that specifies air mass and moisture fluxes.
- FY-86: Implementation and testing of new radiative transfer package.
Implementation and testing of new convective prescription.
Application studies with improved CCM.

Distribution

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23 December 1983

Drs. Michael MacCracken and Cecil Leith
Lawrence Livermore National Laboratory
L-13, P. O. Box 808
Livermore, CA 94550

Dear Mike and Chuck:

I enjoyed our meeting at Livermore on Dec. 6 and the chance to have Starley Thompson, Jeff Kiehl, V. Ramaswamy and I show you our early modeling results in the study of potential climatic effects of smoke and dust veils generated by hypothetical nuclear war scenarios. This letter follows up on your request to me at our Dec. 6 meeting to present a brief overview of how NCAR scientists could, with some help from Lawrence Livermore National Laboratory, enhance the capability of one present version of the NCAR Community Climate Model (CCMOB) to more reliably simulate nuclear smoke and dust aerosols. Since our meeting and the presentations made at the AGU session the following day, we have held many internal meetings and written several draft plans. There have been wide discussions by members of the Climate Section, the CCM core group, the CCM steering committee, and the Advanced Study Program. Also involved in these discussions have been the AAP Director, the Director of NCAR, the President of UCAR, and Gene Bierly of the NSF. We have developed an outline of a comprehensive NCAR program to enhance the CCMOB for applications to climate change experiments in general, and nuclear war aerosols in particular. The program would focus on model development in areas that are particularly critical to surface climatic response to radiative perturbations, sub-grid scale vertical transport of energy and mass in the boundary layer and free atmosphere and on transport and removal of aerosols (see Attachment A). NCAR is willing to support a considerable fraction of this effort through the continuing contribution of scientific staff, programmers and computer time. However, rapid progress in the schedule of CCM enhancement for the nuclear war/climate problem will require outside funding of scientific staff, computer time and equipment. In particular, we will need help from LLNL to support the addition of experts in the first three scientific areas on Attachment A (i.e., radiative transfer; planetary boundary layer and surface processes; and sub-grid scale vertical convection) as well as for computer time.

Very roughly, in FY84 we estimate the need for LLNL support of 0.25 FTE for a Scientist I level position in planetary boundary layer work (S.L. Thompson) as well as 0.05 FTE for a senior scientist (R.E.

Dickinson). NCAR would contribute roughly 0.25 and 0.10 FTE respectively to support these scientists' work on CCM development relevant to nuclear war/climate studies. Management, travel and computer time requests (about 10 CCUs) would bring the LLNL FY84 share to approximately \$50,000.

For each of FY85 and FY86, the following are tentative examples of NCAR and LLNL cost sharing:

Proposed Funding in FY85 and FY86 (tentative examples)

<u>Personnel</u>	<u>FTEs</u>
Junior-level Scientists	1.5
Senior-level Scientists	0.5
Management	0.1
Programming	1.0
Secretarial	0.2
	<u>3.3</u>

Personnel Cost including benefits and overhead: about \$200K per year.

Cray-1 computer resources (about 150 low-priority CPU hours per year for model development): about \$100K per year.

Total LLNL funding: about \$300K per year.

NCAR commitment

NCAR would more than match LLNL's support of model enhancements by its CCM development efforts by the equivalent of \$400K per year in FY85 and FY86. (E.g., the \$100K funding by LLNL for Cray-1 time represents less than half of the resources that will be required for model development and control runs.) NCAR will seek outside funding from additional sources to cover a portion of this expanded effort.

These examples are, of course, preliminary estimates in very round numbers. We look forward to your reactions to them. We would be very happy to provide a more formal and detailed proposal of our plans once we've received your remarks on the research.

With regard to management and scientific direction, Bob Dickinson and I have agreed to be co-principal investigators of any outside proposals. Scientific consultation from senior members of the NCAR Climate and Large Scale Dynamics Sections would also help to maintain the scientific quality of new model development efforts. Final arrangements, however, between NCAR and LLNL would, of course, have to be approved by the NCAR Director, appropriate NSF managers, and appropriate LLNL officials.

I hope you find this letter responsive to your original request,
and look forward to your response.

With regards,

Stephen H. Schneider
Deputy Director,
Advanced Study Program

SHS:brm

attachment

cc: R. Anthes
R. Dickinson
W. Hess
S. Thompson
W. Washington

ATTACHMENT A

Proposed CCM Enhancements

1. Radiative transfer. The radiative transfer package presently in the CCM does not allow for incorporation of scattering aerosols such as nuclear war generated smoke or dust. It is proposed to develop a new radiative transfer capability for use in nuclear war/climate studies and other important aerosol/climate problems (e.g., volcanic dust, cloud droplets). A primary goal would be to incorporate a highly modular package having much improved flexibility for all types of atmospheric radiative transfer problems and the capability of easy modification. The programs would be tested in one-dimensional models before inclusion in the general circulation model. It is anticipated that this work would take 2 to 3 years.

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of aerosols is a difficult microphysical problem that will no doubt require successive generations of parameterizations of increasing refinement. Little is known about how a three-dimensional GCM will react to a strongly radiatively active patchy tracer substance. For this reason crude preliminary tracer simulations should also be performed, perhaps using the present spectral formulation, in order to develop intuition about model behavior and to attempt to uncover any model problems that may need attention before detailed tracer studies can be performed. Since LLNL would use a separate tracer model developed in-house, LLNL would not be expected to support the development of tracer capabilities in the GCM.

5. High-Resolution CFM Studies. It would be desirable to perform simulations with a high-resolution (around 100 km) model in order to test the sensitivity of the results of nuclear smoke simulations to model resolution. Such simulations could more accurately depict transient smoke sources and smoke movement and diffusion than standard model runs. They also would be useful in checking the resolution dependence of rainfall removal processes by more direct simulation of mesoscale rainfall and the possible influence of mesoscale circulations generated along smoke boundaries. The length of the simulations would have to be relatively short to avoid excessive computer resource use. This effort could be conducted with the NCAR mesoscale model nested within the Community Forecast Model (CFM) and conducted with the Regional Acid Deposition Modeling Project.

NCAR Proposal No. 84-4.1

A CONTINUATION
OF
RESEARCH ON CLIMATIC EFFECTS
OF
NUCLEAR WAR

"CCM ENHANCEMENT"

to be carried out by NCAR
with support from the
DEPARTMENT OF ENERGY
for
LAWRENCE LIVERMORE NATIONAL LABORATORY

Principal Investigators:
Robert E. Dickinson
and
Stephen H. Schneider

July 1984

CCM ENHANCEMENT

As an update of NCAR proposal #84-4 submitted last January for FY84, this letter describes the proposed FY85 effort that NCAR is asking Lawrence Livermore National Laboratory to support to speed up the development of the Community Climate Model (CCM) parameterizations needed to improve projections of the climatic effects of nuclear war. The proposed work is to be carried out within the Atmospheric Analysis and Prediction Division of NCAR. A related grant from the Defense Nuclear Agency, primarily in NCAR's Advanced Study Program, will be supporting related studies of the climatic effects of nuclear war.

The work proposed here will be only a small fraction of NCAR's total effort devoted to improving the CCM and to studying the climatic effects of nuclear war. However, it should contribute significantly to both objectives. We are already committed to making available to the general community of CCM users model improvements in physics and code structure after they have been adequately tested and studied by their originators. Through collaborative work and close communication, Lawrence Livermore scientists will be among the first of outside users to obtain improvements that would increase our confidence in simulations of climate change resulting from nuclear war.

The following is a description of the tasks, personnel, and proposed budget for the FY85 effort at NCAR that Lawrence Livermore is being asked to support. We will be happy to provide brief letter

reports on about a three-month basis after the requested funds have been provided to NCAR and to report by phone whenever any significant new developments occur. Funding for future years will be essentially at this same level.

1. Planetary boundary layer, surface processes, and implementation of a diurnal cycle (continues FY84 proposed work)
(R. Dickinson, P. Kennedy)

A simple PBL model has been developed. It will be further tested including the effect of adding more layers to the lowest model levels. Computer code for a diurnal cycle will be meshed with the existing radiation package. A detailed surface physics parameterization, now in the process of being linked to the CCM, will be further tested for errors and used in some simulations to identify possible defects. We will start to collect and incorporate into the CCM surface property data sets required by the surface physics parameterizations.

2. Subgrid-scale cumulus convective parameterizations
(L. Donner)

Various cumulus parameterizations will be developed and tested in the CCM. These parameterizations will provide estimates of the vertical redistribution of heat and moisture. Their application to vertical transport of momentum and mass will also be considered.

3. Large-scale moisture transport parameterization (P. Rasch)

One of the serious current defects in the CCM is its treatment of water vapor, especially in high latitudes where, in spite of massive "filling," large regions of negative mixing ratios are still obtained. A number of different transport schemes besides that now being used will be incorporated into the CCM and tested.

4. Documentation of radiation code (J. Kiehl)

One of the most difficult aspects of the CCM for outside users to work with is the radiation and cloud subroutines. These are very complex and not coded in a form compatible with the rest of the code. Recoding of the existing routine into the standard CCM form is not now possible because of lack of code documentation. A report documenting the radiation code will be completed as a necessary preliminary step before improved radiation parameterizations can be developed and provided to outside users.

5. Implement seasonal cycle in CCM08 and test new parameterizations in a seasonal cycle mode (R. Charvin)

The now standard supported CCM version (CCM08) is only set up to do either perpetual January or July simulations. For most climate studies, seasonal cycle simulations allow more confidence in the results obtained. To implement a seasonal cycle requires modifications in the radiation routine and organization of data sets for sea ice, ocean surface temperature, and ozone path lengths.

Personnel and Budget Breakdown

SALARIES

	<u>Effort</u>	<u>\$</u>
R. Chervin	0.20	\$ 9,000
R. Dickinson	0.25	16,300
L. Donner	0.20	6,000
P. Kennedy	0.20	7,400
J. Kiehl	0.20	6,800
P. Rasch	<u>0.20</u>	<u>6,000</u>
	1.25	\$ 51,500
<u>BENEFITS</u> (24.5%)		<u>12,600</u>
Subtotal:		64,100
<u>MATERIAL & SUPPLIES</u>		600
<u>PURCHASED SERVICES</u> (postage, communication, etc.)		1,000
<u>TRAVEL</u>		<u>3,000</u>
Subtotal:		\$ 68,700
<u>OVERHEAD</u>		
Division Burden (21.54%)*		<u>14,800</u>
Subtotal:		\$ 83,500
General & Administrative (19.72%)*		<u>16,500</u>
TOTAL:		<u>\$100,000</u>

*Indirect rates for FY 85 and beyond are provisional and subject to change pending NSF approval.

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7 September 1984

Dr. Michael C. MacCracken
Atmospheric and Geophysical
Sciences Division
Lawrence Livermore National
Laboratory
P. O. Box 808
Livermore, CA 94550

Dear Mike:

I am replying to your request for a progress report on the FY84 NCAR effort supported by Lawrence Livermore. The proposed work was stated to be: "Additional work relevant to the nuclear smoke question will begin in FY84 on including a combination PBL parameterization and enhance surface physics package in the CCM so that detailed time and space evolution of surface temperature can be reasonably trusted."

To date, I have developed the required linkage mode for a first attempt at carrying out the proposed work, with the help of a research assistant, Pat Kennedy. All obvious bugs have been removed with some help from S. Thompson, and we are in the process of developing longer (20-60 day) simulations to look for more subtle bugs or evidence of undesirable features. This will require computing difference plots between standard model control runs and new version simulations, and is being carried out in collaboration with S. Thompson. This phase is expected to be completed by the end of the calendar year.

Other related activities expected to be pursued in the next few months are to develop an annual cycle capability, to add further model layers to better resolve the PBL and to improve the now rather poor model data base for land surface type prescription. Naturally, much of this is co-supported by our ongoing program.

Yours,

Robert E. Dickinson

cc: S. Schneider

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21 March 1985

Dr. Michael MacCracken
Area Manager, Climate
Lawrence Livermore National
Laboratory
Mail Stop L-262
Box 808
Livermore, CA 94550

Dear Mike:

This is a letter report on progress made on the project, "A Continuation of Research on Climatic Effects of Nuclear War," carried out by NCAR with support from LENL.

We proposed work in five areas. Progress is as follows:

1. Planetary boundary layer, surface processes, diurnal cycle

Most aspects of our planned treatment have now been incorporated into the CCM and extensively tested, including a seven-month annual cycle simulation from January to July. Still being implemented is incorporation of a global data set for soils hydrological and albedo properties. This aspect is now being done with the help of Maureen Wilson, ASP postdoc, and Ann Henderson-Sellers, AAP visitor. We then plan to establish a five-year (five annual cycles) control run and carry out several sensitivity studies, some involving nuclear winter scenarios.

With some further programming assistance, these new packages could be made available to other users within a year's time.

2. Subgrid-scale cumulus convective parameterizations

Donner continues to work on this topic. Further details will be given in my next report.

3. Large-scale moisture transport parameterizations

Rasch has tested several alternative numerical schemes, but none has yet proved superior to the standard treatment.

4. Documentation of the radiation

Progress on this task has been delayed because Ramanathan has developed a new improved version of the radiation code that will probably be incorporated into future versions of the CCM.

Dr. Michael MacCracken

Page 2

21 March 1985

5. Implementation of season cycle

Chervin, Boville, and Bath have developed a code to add the seasonal cycle to the standard CCM3. A version of this code, modified for diurnal cycle and albedo changes, is being used for the work described in item 1.

Other remarks: Williamson has developed a 12-layer version of CCM3 that essentially eliminates the departures from thermal energy conservation found in the standard model version.

There have been some complaints about computer tapes going to LLNL without being returned. Purchasing replacements out of the grant seems to be a possible solution if it is inconvenient for the tapes to be returned from Livermore.

If you have any further questions, please call.

Yours,

Robert E. Dickinson

cc: R. Anthes
S. Schneider
S. Thompson
D. Williamson

NCAR Proposal No. 84-4.2

**A FURTHER CONTINUATION
OF
RESEARCH ON CLIMATIC EFFECTS
OF
NUCLEAR WAR**

~~"CCM ENHANCEMENT"~~

to be carried out by NCAR
with support from the
DEPARTMENT OF ENERGY
for
LAWRENCE LIVERMORE NATIONAL LABORATORY

Principal Investigators:
Robert E. Dickinson
and
Stephen H. Schneider

August 1985

CCM ENHANCEMENT

As an update of NCAR proposals #84-4 and #84-4.1 submitted in January 84 and August 84, this letter describes the proposed FY86 effort that NCAR is asking Lawrence Livermore National Laboratory (LLNL) for support to speed up the development of the Community Climate Model (CCM) parameterizations needed to improve projections of the climatic effects of nuclear war. The proposed work is to be carried out within the Atmospheric Analysis and Prediction and Advanced Study Divisions of NCAR. A related grant from the Defense Nuclear Agency, in NCAR's Advanced Study Program, will be supporting related studies of the climatic effects of nuclear war.

The work proposed here continues to be only a small fraction of NCAR's total effort devoted to improving the CCM and to studying the climatic effects of nuclear war. However, it should contribute significantly to both objectives. We are already committed to making available to the general community of CCM users model improvements in physics and code structure after they have been adequately tested and studied by their originators. Through collaborative work and close communication, LLNL scientists are and will be among the first of outside users to obtain improvements that would increase our confidence in simulations of climate change resulting from nuclear war.

A virtual IBM machine has been set up at NCAR to expedite code communications with LLNL. Code that will be available upon request to LLNL by FY86 includes an energy and moisture conservative vertical difference scheme developed by David Williamson, a single scattering fast aerosol code developed by Starley Thompson, and a negative moisture fix, discussed in item 3 below. Many further improvements being developed over the next year are being tested in a 12-layer "CCMOC" version of the model which may not be publically released. Listings of such modifications can be given to LLNL scientists upon

request, if they want to attempt their integration into their CCMOB code. Otherwise, we anticipate that the first large augmentation to LLNL's code will occur when a CCM1 package is released in about a year's time. This code will include improvements developed under contract support.

The following is a description of the tasks, personnel, and proposed budget for the FY86 effort at NCAR that Lawrence Livermore is being asked to support and also summarizes progress and results obtained under the FY85 proposal. We will provide brief letter reports on about a four-month basis after the requested funds have been provided to NCAR.

1. Planetary boundary layer, surface processes, and implementation of a diurnal cycle (continues FY85 proposed work) (R. Dickinson and P. Kennedy)

A simple vertical diffusion depending on Richardson number has been tested and found to be unstable when extended above 500 mb. This scheme provides a satisfactory normal PBL but cannot yet be used for above smoke cloud convection of nuclear winter scenario. The cause of this instability will be identified and fixed. Computer code for a diurnal cycle has been meshed with the existing radiation package. With assistance from Maureen Wilson and Ann Henderson-Sellers, we have incorporated into the CCM land use and soils data sets required by the surface physics parameterizations.

All these modifications of the model developed over the last year have been tested by a simulation over three seasonal cycles. This simulation will be analyzed in detail; but preliminary examination indicates that: (a) the model atmosphere zonal mean climatology is quite good, significantly improved over the standard CCMOB model; (b) the surface temperatures look quite good in low to middle latitudes; and (c) in high latitudes, surface temperatures are too cold in winter, and Northern Hemisphere high latitude surface temperatures are too warm in summer. The winter high latitude problem is probably mostly a result of the unrealistic model humidities resulting in a shortage of clouds. Fixes developed under item 3 below will be tested to see if this is the case. The excess summer temperature

is in part also a result of deficit in cloudiness. In addition, the model is too warm because of lack of a permafrost melting heat sink and neglect of poorly drained and swampy land. These features will be added. We are budgeting a trip for Ann Henderson-Sellers from England for summer 1986 to help pursue these and other surface physics related problems.

2. Subgrid-scale cumulus convective parameterisations (L. Donner)

Kuo-type cumulus parameterizations have been developed and tested in the CCM for climate simulations and are being tested in a short-range forecast mode. These parameterizations provide estimates of the vertical redistribution of heat and moisture. These parameterizations at present somewhat degrade the model climatology. The question as to whether this is caused by the parameterizations themselves or other model problems will be explored.

3. Large-scale moisture transport parameterisation (P. Rasch)

One of the serious current defects in the CCM is its treatment of water vapor, especially in high latitudes where, in spite of massive "filling," large regions of negative mixing ratios are still obtained. A number of different transport schemes besides that now being used but in the model spectral framework have been incorporated into the CCM and tested. None gave any improved results. Schemes outside the spectral framework will now be examined.

The most successful "fix" of the high latitude humidity problem developed so far is a global filling scheme, which makes high latitude humidities more realistic and warms January temperatures by about 5°. This scheme will be tested in the seasonal cycle surface physics model. This code can also be released to LLNL staff upon request.

4. Documentation of radiation code and incorporation of improved radiation package into CCM1 (J. Kiehl)

One of the most difficult aspects of the CCM for outside users to work with is the radiation and cloud subroutines. These are very complex and not coded in a form compatible with the rest of the code. Recoding of the existing routine into the standard CCM form is

not now possible because of lack of code documentation. A draft set of notes documenting the radiation code has been completed as a necessary preliminary step before improved radiation parameterizations can be developed and provided to outside users and is enclosed. A new radiation scheme developed by Ramanathan is now being tested and will become part of the next frozen model version, CCM1, expected to be available in about a year's time. Further documentation effort will be directed toward this code.

b. Implement seasonal cycle in CCMOB and test new parameterisations in a season cycle mode (task completed in 1985)

The now standard supported CCM version (CCMOB) is only set up to do either perpetual January or July simulations. For most climate studies, seasonal cycle simulations allow more confidence in the results obtained. A seasonal cycle set of mods has been developed including modifications in the radiation routine and organization of data sets for sea ice, ocean surface temperature, and ozone path lengths. These are available to LLNL staff upon request.

BUDGET
1 October 1935 thru 30 September 1986

	% Effort	\$
SALARIES:		
R. Dickinson	0.25	\$ 16,100
L. Donner	0.20	6,100
P. Kennedy	0.10	3,700
J. Kishl	0.20	6,600
P. Rasch	0.20	6,100
D. Williamson	0.10	5,300
Subtotals:	1.05	\$ 43,900
 BENEFITS (24.5%):		
		10,800
Subtotal:		\$ 54,700
 MATERIALS & SUPPLIES:		
		100
 PURCHASED SERVICES (postage, communications, masscomp, etc.)		
		10,000
 TRAVEL:		
		6,000
Subtotal:		\$ 70,800
 OVERHEAD:		
Division Burden (19.64%)*:		13,900
Subtotal:		\$ 84,700
General & Administrative (18.01%)*:		15,300
TOTAL:		\$100,000

 *Indirect rates for FY86 and beyond are provisional and subject to change pending NSF approval.

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25 October 1985

Dr. Michael C. MacCracken
 Deputy Division Leader
 Atmospheric and Geophysical
 Sciences Division
 Lawrence Livermore National Laboratory
 P.O. Box 808
 Livermore, CA 94550

Dear Mike:

This letter is to clarify the NCAR Climatic Effects of Nuclear War-CCM Enhancement proposal as you requested. I wish to again iterate that your support adds a modest increment to what are already high-priority research items for AAP's scientists and, because they are research, we cannot guarantee deliverable products before their time. However, it also means there are likely to be other products that we have not mentioned or anticipated that would be more valuable to you than those in the proposal. I suggest that arrangements be made for either a workshop or individual visits to Livermore by scientists supported by the proposal some time next spring to further clarify at that time what has been developed that would be of most use to you.

Enclosed is a list of our current best guess as to CCM modification packages that would be available to LLNL over the next year.

In response to your questions, an ocean mixed-layer model has not been developed for the supported CCM0 but is expected to be in the next year. I have added the Ramanathan package to the list, to be provided either as mode for CCM0 or as part of the CCM1, if that is ready by then. Its primary emphasis is on needed improvements in the treatment of clear-sky radiation; since the current treatment of water vapor in the lower stratosphere is terrible, this package should make a significant difference for nuclear winter simulations. We cannot yet clarify what code for aerosols would be included.

Both vertical and horizontal differencing are being considered for improvements in the water vapor treatment, but the only item yet near completion is the "quick fix" global borrowing scheme developed by Williamson and Rasch. You are correct in assuming that work on the Kuo scheme and other convective parameterization work at NCAR is emphasizing subgrid-scale vertical moisture transport and would be a crucial input to any future scavenging scheme.

Let me know if you have any further questions.

Yours,

Robert Dickinson
 Robert E. Dickinson

Enclosure

CCM MODIFICATION PACKAGES EXPECTED
TO BE AVAILABLE FOR LLNL
DURING FY-86

1. Currently available modifications
 - a. Williamson energy-conserving vertical differencing scheme.
 - b. Seasonal cycle with prescribed SST.
 - c. Fast, single-scatter aerosol solar radiation package.
2. Expected to be available by April, 1986.
 - a. Preliminary version of PBL, vertical diffusion package plus mode to add, diurnal cycle of radiation.
 - b. Global filling fix for negative water vapor mixing ratios.
3. Expected to be available before October, 1986.
 - a. Update, if needed, of item 2a.
 - b. Preliminary realistic treatment of surface physics processes.
 - c. Ramanathan radiation package.
 - d. Large-scale horizontal and vertical moisture flux differencing scheme.
 - e. Mixed-layer ocean.
 - f. Draft documentation for 2a and 3b.

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2 May 1986

Dr. Michael C. MacCracken
Deputy Division Leader
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Sciences Division
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Dear Mike,

To add to my letter of 25 October 1985, here is a progress report on where we stand at NCAR with respect to the CCM enhancements for pursuing research on the effects of nuclear war on the atmosphere. The grant money for this year is now at NSF and should arrive at NCAR shortly.

I have been working with Pat Kennedy on the new surface physics package and we have carried out several sensitivity studies in collaboration with Henderson-Sellers and Wilson of the UK. Enclosed are drafts of two manuscripts resulting from this collaboration. A new documentation for this part of the CCM including treatment of soils is being prepared and will be sent to you as soon as possible, probably this summer.

Leo Donner has investigated the thermodynamic and dynamic interactions between cumulus convection and large-scale flows. He analyzed the impact on the thermodynamic balance of the NCAR CCM of a version of the Kuo cumulus parameterization scheme and found a strong interaction between cumulus convection and radiative forcing through cloud feedbacks. This study also suggested that excessive cooling and drying of the lower tropical troposphere due to the Kuo scheme required substantial reformulation of the parameterization for deep cumulus convection, which is being accomplished through a scheme integrating explicitly over the lifetime of the cumulus ensemble. A parameterization for the generation of large-scale vorticity by cumulus convection has also been developed.

Philip Rasch has been developing a scheme for scalar transport using a technique known as Flux Corrected Transport (FCT), for integration into the CCM. FCT is a hybrid scheme which combines solutions found by a high and low accuracy technique in a fashion designed to exploit the best characteristics of both. Early implementations of FCT were done in a Cartesian geometry on an equidistant grid, or using a one-dimensional framework with time splitting to handle multi-dimensional problems. Here, FCT is being extended to make FCT function in a spherical geometry on a non-equidistant (Gaussian) grid. Spectral and Donor Cell techniques have been used for the high and low accuracy parts respectively. The scheme has been implemented in a simple test-bed, a continuity equation on the sphere with a nondivergent velocity field which advects the scalar across the poles. The scheme shows promise in this setting but the spherical coordinates have a singularity at the poles which result in significant problems there for almost any scheme, requiring great care to be taken. The latest results with FCT are encouraging, but it is not yet clear whether all the problems are resolved.

J. T. Kiehl has been working on restructuring all of the radiation routines in the CCM. In the process of this code restructuring, both internal and external documentation are being added to the CCM. The present status of this work is that the radiation part of the CCM has now been separated into shorter and more readable subroutines. Within each of these subroutines, internal documentation including references to published works describing the physical parameterizations has been added. Notes on the numerical algorithms used to solve the radiative transfer equation have also been added to each subroutine. The final phase of the code restructuring will be external documentation of the radiation code. This will be completed within the next two months, and will appear in the form of an NCAR technical note. The purpose of the external documentation will be to provide users a description of the physical parameterizations used in the radiation routines.

Dave Williamson has been occupied with finalizing the code for CCM1, which includes several of the improvements I developed earlier such as local Richardson number dependent vertical diffusion and diurnal cycle. As soon as a file is available, we will start incorporating our surface package into CCM1. We expect the NCAR computing environment to remain poor until October because of major disruptions related to installation of a CRAY X-MP. Considerable effort has been required over the last three months in maintenance of codes and data sets in a hostile environment. We expect to be able to provide you with the new CCM1 by next October, and the surface package coupled to it, shortly thereafter. Preliminary codes could be provided earlier if you have a need for them.

Yours,

Robert E. Dickinson

RED/hrh

Enclosures

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3 December 1986

Dr. Michael C. MacCracken
Area Manager, Climate
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Livermore, CA 94550

Dear Mike:

This letter is intended to represent the final report for the grant to NCAR from Lawrence Livermore National Laboratory to support work of the NCAR Community Climate Model. It updates the previous 2 May 1986 report and indicates further materials to be delivered when available.

The new surface package (BATS) has been documented through in-code comments and a detailed technical note (Ref. 1). The technical note is in press, and several copies will be mailed as part of this report as soon as available (by January 1987). An offline version of the current code is available to you upon request. The version running with CCM0 is not maintained, but efforts are now devoted to completing conversion to the new CCM1. We expect this task to be complete in about two months, after which the CCM1 appropriate code, including diurnal cycle, can be sent you upon request (this includes the offline version).

Work by Leo Donner on the cumulus parameterisation in the CCM (Ref. 3), partially supported by the grant, will appear in the 1 November 1986 issue of *The Journal of the Atmospheric Sciences*, and reprints will be forwarded when ready.

The efforts by Philip Rasch to use a Flux Corrected Transport technique for scalar transport in the CCM revealed severe difficulties at the poles, and the work was abandoned.

J.T. Kiehl has continued to work on improving the radiation routines in the CCM. These efforts have been incorporated into the new CCM1 code and its supporting documentation (Ref. 2), the latter still in preparation.

Dave Williamson is almost finished finalizing the CCM1 code and expects to have a code description (Ref. 2) and all other documentation complete in time for the CCM external Advisory Committee at the end of January. The code files for CCM1 should be frozen within the next month, after which they can be supplied to you upon request.

Yours,

Robert E. Dickinson

Enclosure

DOCUMENTATION TO BE SENT LATER

1. Dickinson, R. E., A. Henderson-Sellers, P. J. Kennedy, and M. F. Wilson, 1986: *Biosphere-Atmosphere Transfer Scheme (BATS) for the NCAR Community Climate Model*. NCAR Technical Note, National Center for Atmospheric Research, Boulder, Colorado, in press.
2. Williamson, D. L., J. T. Kiehl, V. Ramanathan, and R. E. Dickinson, 1987: *Description of NCAR Community Climate Model (CCM1)*. NCAR Technical Note, National Center for Atmospheric Research, Boulder, Colorado, in preparation.
3. Donner, L.J., 1986: The sensitivity of the thermal balance in a general circulation model to a parameterization for cumulus convection with radiatively interactive clouds. *Journal of the Atmospheric Sciences*, in press, November 1986.

List of Publications and Reports*

- Dickinson, R.E., A. Henderson-Sellers, P.J. Kennedy, and M.F. Wilson, 1986: *Biosphere-Atmosphere Transfer Scheme (BATS) for the NCAR Community Climate Model*. NCAR Technical Note, National Center for Atmospheric Research, Boulder, Colorado, in press.
- Williamson, D.L., J.T. Kiehl, V. Ramanathan, and R.E. Dickinson, 1987: *Description of NCAR Community Climate Model (CCM1)*. NCAR Technical Note, National Center for Atmospheric Research, Boulder, Colorado, in preparation.
- Donner, L.J., 1986: The sensitivity of the thermal balance in a general circulation model to a parameterization of cumulus convection with radiatively interactive clouds. *Journal of the Atmospheric Sciences*, in press, November 1986.
- Kiehl, J.T., C. Brühl, and T. Yamanonchi, A parameterisation for the absorption due to the near infrared bands of CO₂. *Tellus*, 37B, 189-196, 1985.