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# Contribution to: SciDAC Progress Report - Collaborative Design and Development of the Community Climate System Model for Terascale Computing

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**SciDAC PROGRESS REPORT**

**Collaborative Design and Development  
of the Community Climate System Model  
for Terascale Computing**

**Department of Energy**

**Office of Biological and Environmental Research**

**Scientific Discovery through Advanced Computing**

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**October 2003**

## 9.0 ATMOSPHERIC CHEMISTRY (TOPIC COORDINATOR: P. CAMERON-SMITH)

### *Background*

Since pre-industrial times, the concentrations of various aerosol types (e.g., sulfate, black carbon, and mineral dust) and several key greenhouse gases such as methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), and ozone (O<sub>3</sub>), have been changing because of anthropogenic activities. Collectively, the magnitude of the climate forcing from these species is larger than that of carbon dioxide (CO<sub>2</sub>) although some are positive and some are negative (see Fig. 27).

The behavior and effect of these non-CO<sub>2</sub> species is more complicated than for CO<sub>2</sub> because they are affected by atmospheric chemistry and aerosol microphysics, so their distributions are more heterogeneous. There are also feedbacks between climate, chemistry, and aerosols that further increase the importance of chemistry and aerosols, *e.g.* a change in any one of stratospheric ozone, stratospheric temperature, or stratospheric dynamics will feedback on the other two. For aerosols, in addition to the direct effect of scattering and absorbing light, they act indirectly by serving as cloud condensation nuclei (CCN), leading to clouds with more (but smaller) droplets that reflect more sunlight and last longer, thus cooling the atmosphere. Aerosols and atmospheric chemistry can also have an impact through interaction with the biosphere, *e.g.*, fertilization of the land with nitrogen species and fertilization of the oceans with Iron from mineral dust. There is also chemical production of CO<sub>2</sub> in the atmosphere through oxidation of species such as CH<sub>4</sub>, CO and turpenes. Thus, to predict and understand future climates, the radiative forcing from these non-CO<sub>2</sub> gases and aerosols, as well as their feedbacks into the radiative, dynamical, and biogeochemical balances, must be taken into account.

The non-CO<sub>2</sub> species are also important because they should be more amenable to anthropogenic control measures trying to mitigate climate change (Hansen *et al.*, 2000) than CO<sub>2</sub> because they have shorter atmospheric lifetimes.

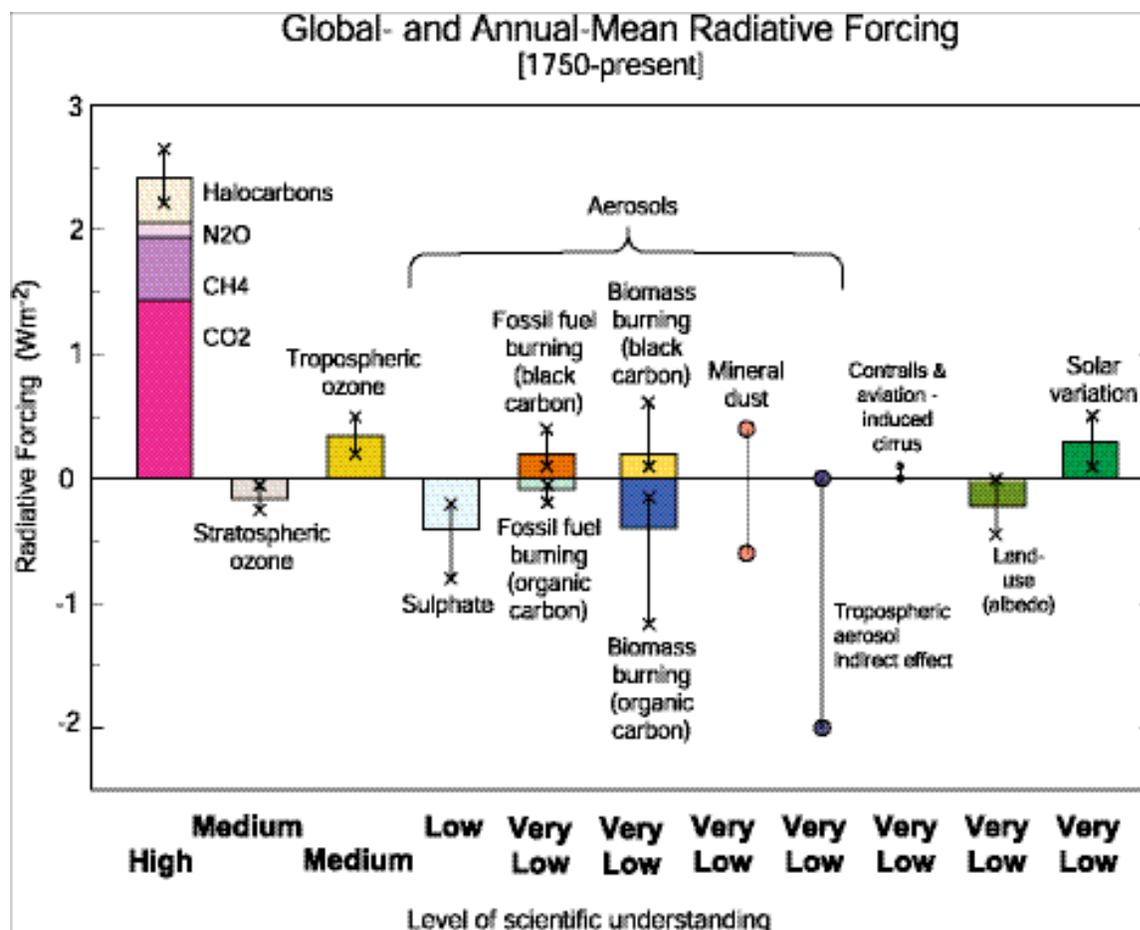


Fig. 27. Global annual mean radiative forcing (Wm<sup>-2</sup>) from IPCC (2001).

### Objectives

Broadly, the goal of this work is to implement interactive ozone photochemistry, methane chemistry, and aerosols into the CCSM in a way that is computationally efficient yet accurate for climate modeling needs. The original objectives were to implement and validate tropospheric-only chemistry in the CCSM model by the end of 2003, followed by implementation and validation of a combined stratosphere-troposphere chemistry capability by the start of 2005, and addition of aerosol microphysics by the end of the project in 2006. This work would leverage the ongoing WACCM effort at NCAR (a combined CGD and ACD effort) and build upon the off-line chemistry models at LLNL (IMPACT model) and NCAR (MOZART model).

The goals also include the implementation in CCSM of MAGPI (a marine aerosol and gas phase interactions code developed by David Erickson at ORNL), and thereby link atmospheric chemistry and sulfate aerosols to ocean biogeochemistry.

The main change from the original plan was to leapfrog the development of a troposphere-only model and directly implement two chemical mechanisms that could simultaneously simulate the stratosphere and troposphere. The first mechanism is small and fast for use in general CCSM simulations, while the second mechanism is more extensive for studying chemistry-climate interactions. This has meant we are now ahead of our schedule for implementing the combined stratosphere-troposphere mechanism in 2005,

and we have two mechanisms instead of one, thereby expanding the utility of chemistry within the CCSM model. There is still considerable work to be done testing and validating the atmospheric chemistry code, particularly with respect to its influence on climate in long 21<sup>st</sup> century simulations where the feedbacks will be strongest.

The objectives for implementing aerosols in the original proposal were fairly general since this work was in the out years and the modeling of aerosols has been advancing. In discussions with Bill Collins (Chair of SSC committee) and Phil Rasch (NCAR) we have identified five long-term aerosol goals for CCSM. . The exact role we will play under SciDAC, and how we can leverage our existing expertise with aerosols in the IMPACT model, is still under discussion. The five aerosol goals are:

1. Adding a bulk formulation for aerosol types that have not yet been implemented completely in CCSM (nitrates, sea-salt, and secondary organics).
2. Introducing size resolved treatments, including microphysics, for all the major aerosols.
3. Treating the mixing state of the aerosols (important for their radiative effects and evolution).
4. Introducing the 1<sup>st</sup> and 2<sup>nd</sup> indirect effects on liquid clouds.
5. Parameterizing the longwave effects of soil dust and possibly sea salt.

We also plan to go beyond the usual method of validating and evaluating aerosol and chemistry models (i.e., comparison of species concentrations with observations) by analyzing the response of the atmospheric model (CAM2) to simulations with and without our additional models using the standard experimental protocol of the Atmospheric Model Intercomparison Project (AMIP simulations are constrained by observed monthly mean sea-surface temperatures and sea-ice, starting in 1979 and run to near-present). Extensive diagnostic tests will be performed on these runs using diagnostic tools developed by the DOE PCMDI, and will be done in collaboration with Peter Gleckler at PCMDI.

This work is well aligned with the objectives of NCAR and CCSM, and has been guided by discussions with Bill Collins (Chair of the SSC committee). The incorporation of both atmospheric chemistry and interactive aerosols into CCSM are major goals of recent CCSM science plans (CCSM science plan 2004-2008, CCSM plan 2000-2005). Indeed, the latest plan (CCSM science plan 2004-2008) states:

- “Because the chemical processes in the troposphere and stratosphere are highly non-linear, it is crucial to have a realistic characterization of the chemical species and their reactions.”
- “Current models ... do not include feedbacks between ozone and dynamics. This deficiency needs to be corrected.”
- “Given the multifaceted roles of aerosols in the climate system, it is imperative that the capability to model a fully interactive aerosol system be developed within CCSM.”

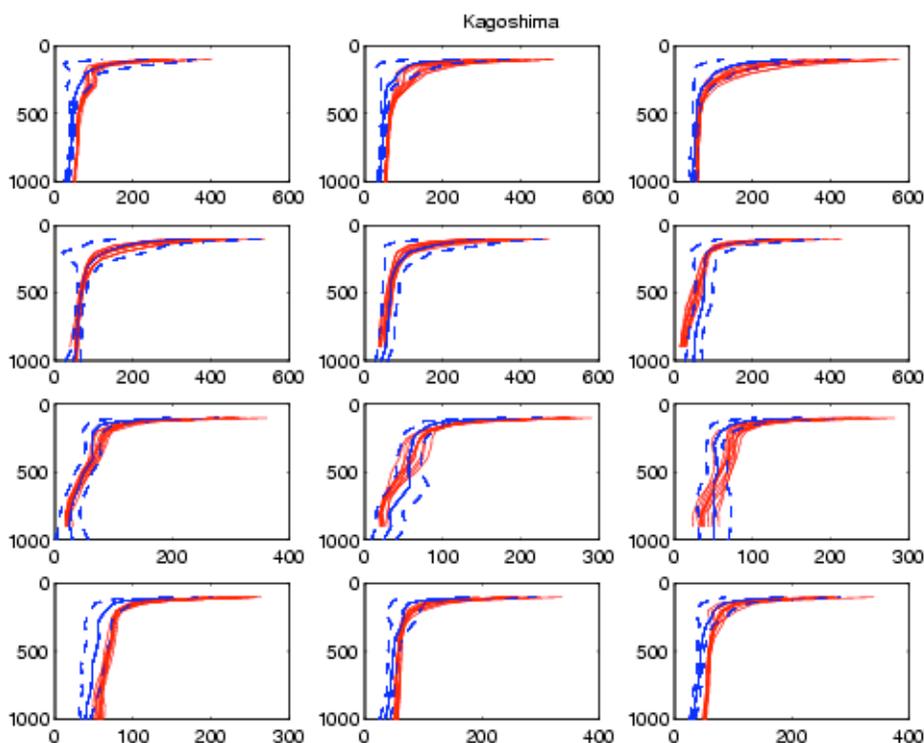
## *Progress*

### **9.1 CCSM DEVELOPMENT (LAMARQUE, WALTERS, KINNISON, MCKENNA)**

A gas-phase chemistry package suitable for tropospheric and stratospheric conditions has been implemented in the WACCM version of CAM2. Simulations were performed and analysis of the results is underway. The chemical scheme offers a complete description of hydrocarbon oxidation in the troposphere and of stratospheric ozone chemistry in the stratosphere. This package includes emissions, deposition (wet and dry), transport (large and subgrid-scale), and photochemical reactions for 106 species. Photolytic reaction rates are calculated using an approach similar to the LLNL Look-Up-Table. Wet and dry deposition algorithms were taken from the MOZART model. All algorithms have been implemented

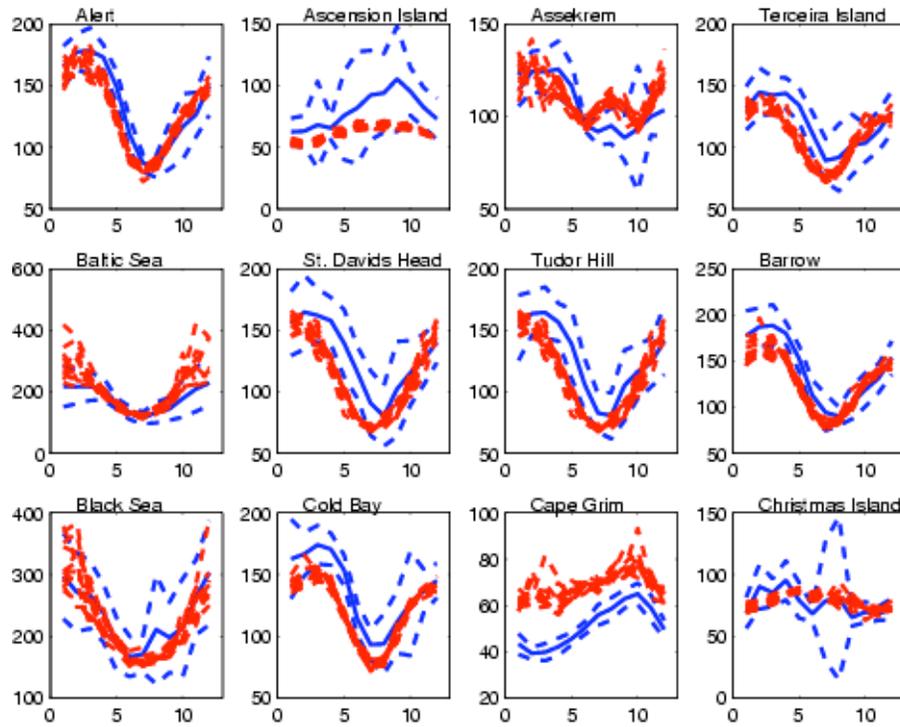
into the WACCM version CAM2. Because our scientific interest is in the troposphere and stratosphere (not higher), we have reduced the model extent to approximately 85 km. This altitude provides a natural boundary across which limited chemical transport occurs. The chemically influenced fields (such as ozone, CFCs, etc.) are fed back to the climate model and used in the radiative calculations.

In the process of integrating interactive chemistry into the climate model, we have performed a set of simulations to evaluate against measurements the performance of the model with interactive chemistry. These simulations were performed at the resolution of  $2^\circ \times 2.5^\circ$  with 52 levels and for 15 years. No drift was found in the simulated ozone field, indicating the lack of misrepresented chemical mechanisms. The analysis of the simulated ozone field (Fig. 28) for a variety of stations indicate that the model is performing very similarly to a tropospheric CTM (MOZART-2) that has the same set of chemical species and reactions. The shortcomings of the simulations are therefore related to problems in emissions and/or chemistry, not in the coupling between the chemistry and the climate models.

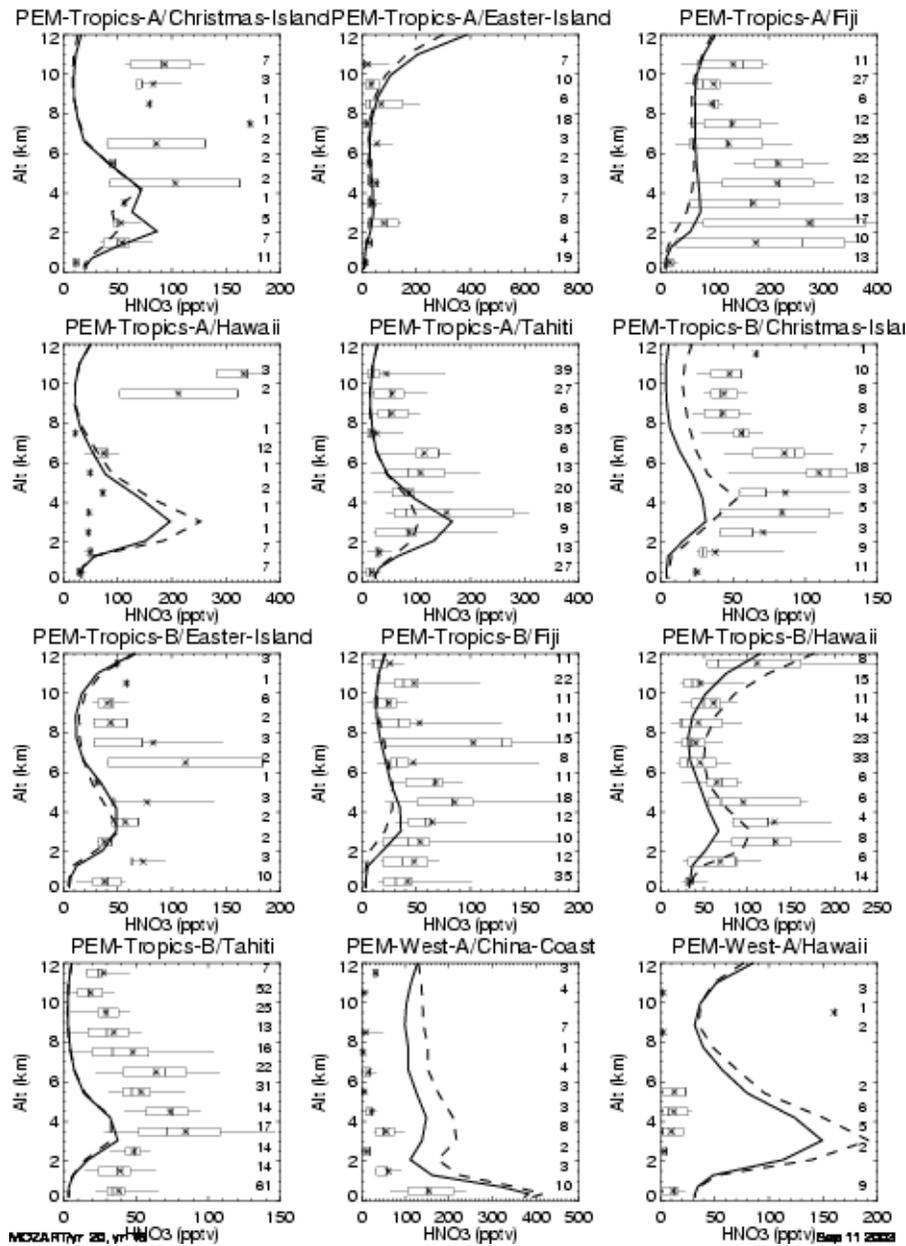


**Fig. 28. Comparison of modeled ozone (red lines, one per simulation year) with ozonesondes data at Kagoshima (Japan) (blue line, dash line is one standard deviation). Each box is per month, January to December (top left to bottom right). Vertical axis is pressure (hPa) and horizontal axis is mixing ratio (ppbv)**

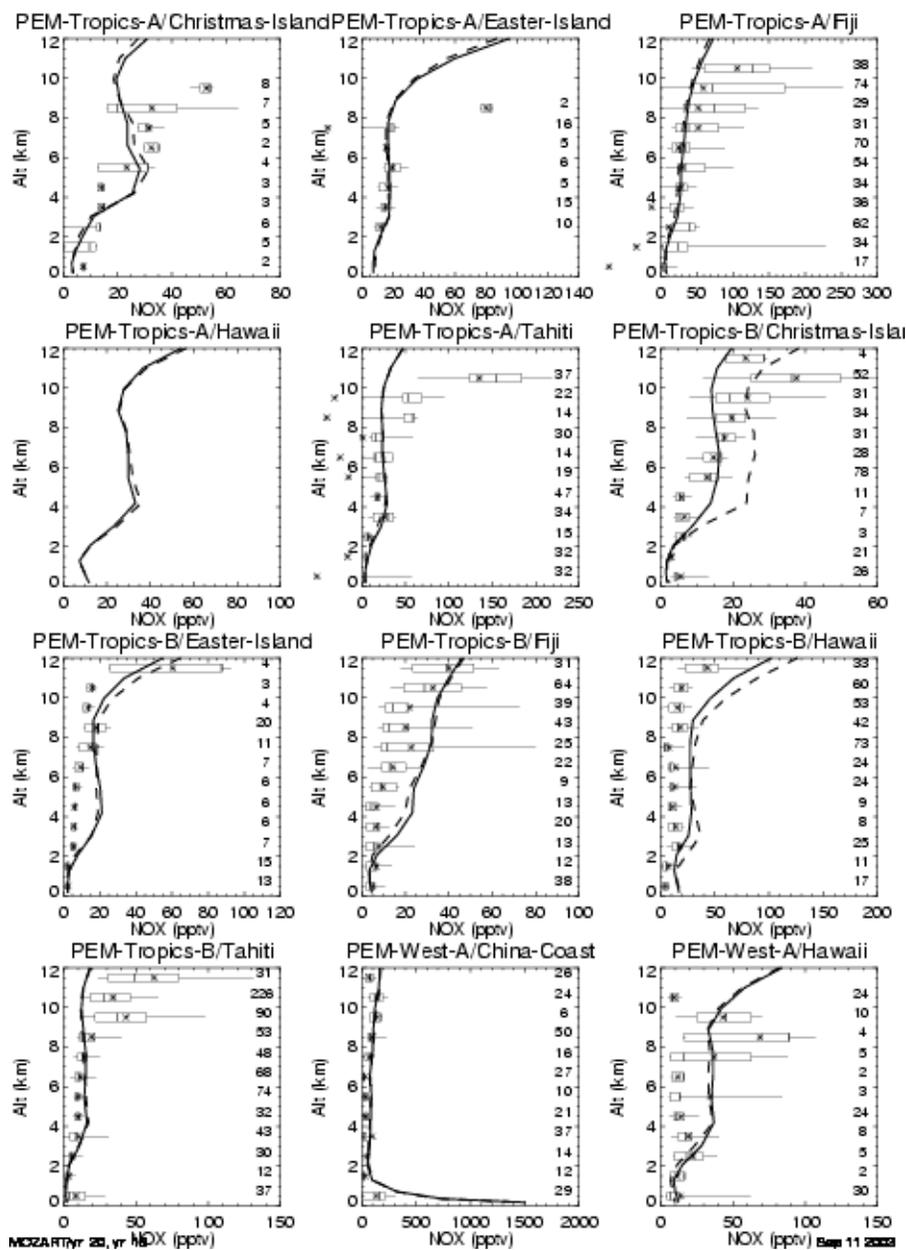
In addition to ozone, we have performed the comparison of the model results for other chemical species against surface (CO from CMDL) aircraft measurements during specific campaigns. These results (Fig. 29, 30, and 31) indicate that the model performs reasonably well in the simulation of more reactive species such as  $\text{NO}_x$ . Evaluation of the stratospheric portion of the model is underway.



**Fig. 29. Comparison of modeled CO (red lines, one per simulation year) with surface CMDL with a variety of stations. Horizontal axis is month of the year and vertical axis is mixing ratio (ppbv)**



**Fig. 20.** Comparison of HNO<sub>3</sub> mixing ratio with selected aircraft campaigns. Solid (dashed) line is model results for year 15 (14). The number of measurements is indicated on the right-hand side of each plot.



**Fig. 31. Comparison of NO<sub>x</sub> mixing ratio with selected aircraft campaigns. Solid (dashed) line is model results for year 15 (14). The number of measurements is indicated on the right-hand side of each plot.**

Although this model is quite expensive to run (it takes approximately one wall-clock day per simulation year on a IBM-SP Power-4 96 CPUs, roughly doubling the cost of the equivalent WACCM model without chemistry), it provides a very realistic description of the average chemical state of the troposphere. This will be the reference to which the reduced mechanism (see below) will be compared.

We are now in the process of having interactive emissions of biogenic VOCs from the CLM used as boundary conditions for this model. This new feature will provide another coupling between chemistry and climate.

## 9.2 CHEMICAL MECHANISM DEVELOPMENT (CAMERON-SMITH, CONNELL, ROTMAN, TANNAHILL)

To enable efficient chemistry simulations within multi-century climate simulations a fast compact chemistry mechanism that simulates both the troposphere and stratosphere has been developed that should provide CCSM with reasonable heating rates due to atmospheric chemistry. Since it is physically based it should also respond reasonably under altered climate conditions.

Since the last report in December 2002 we have improved the fidelity of the compact mechanism (previously the compact mechanism was only within a factor of 2 in the troposphere and now it agrees within 20%), and ported the compact mechanism to the CCSM where it is undergoing testing. We have also implemented long and short wave radiation packages into the IMPACT model so we can validate the heating rates being generated by the chemistry within CCSM once the compact mechanism is running.

The compact mechanism was developed by paring down our state-of-the-art chemistry mechanism (named TS2), which includes Ox, HOy, NOy, ClOy, BrOy, SOx, and VOC chemistry for both the troposphere and stratosphere, in a way that realistically calculates ozone around the tropopause, where it produces the greatest radiative forcing. The compact mechanism (named TS4) includes essential HOx and NOy reactions, is 4 times smaller and faster than our full mechanism (TS2), and covers both the troposphere and stratosphere.

The magnitude of the overhead ozone is very important when calculating photolysis rates. With the full mechanism (TS2) we use the ozone field calculated by the IMPACT model (Rotman, *et al.*, 2003), so the model is fully interactive in this respect. However, with the small mechanism (TS4) we were concerned that a less accurate ozone field might feedback onto photolysis rates. Hence, we tested the small mechanism using both its own ozone field and ozone climatology for photolysis (the photolysis package used in IMPACT is the Look-Up-Table as used above in the CAM runs).

To test the compact mechanism we ran three 10-year simulations in the IMPACT model:

- A) Compact mechanism (TS4), using the ozone field it generates for photolysis rates.
- B) Compact mechanism (TS4), using the ozone climatology for photolysis rates.
- C) Full mechanism (TS2), using the ozone field it generates for photolysis rates.

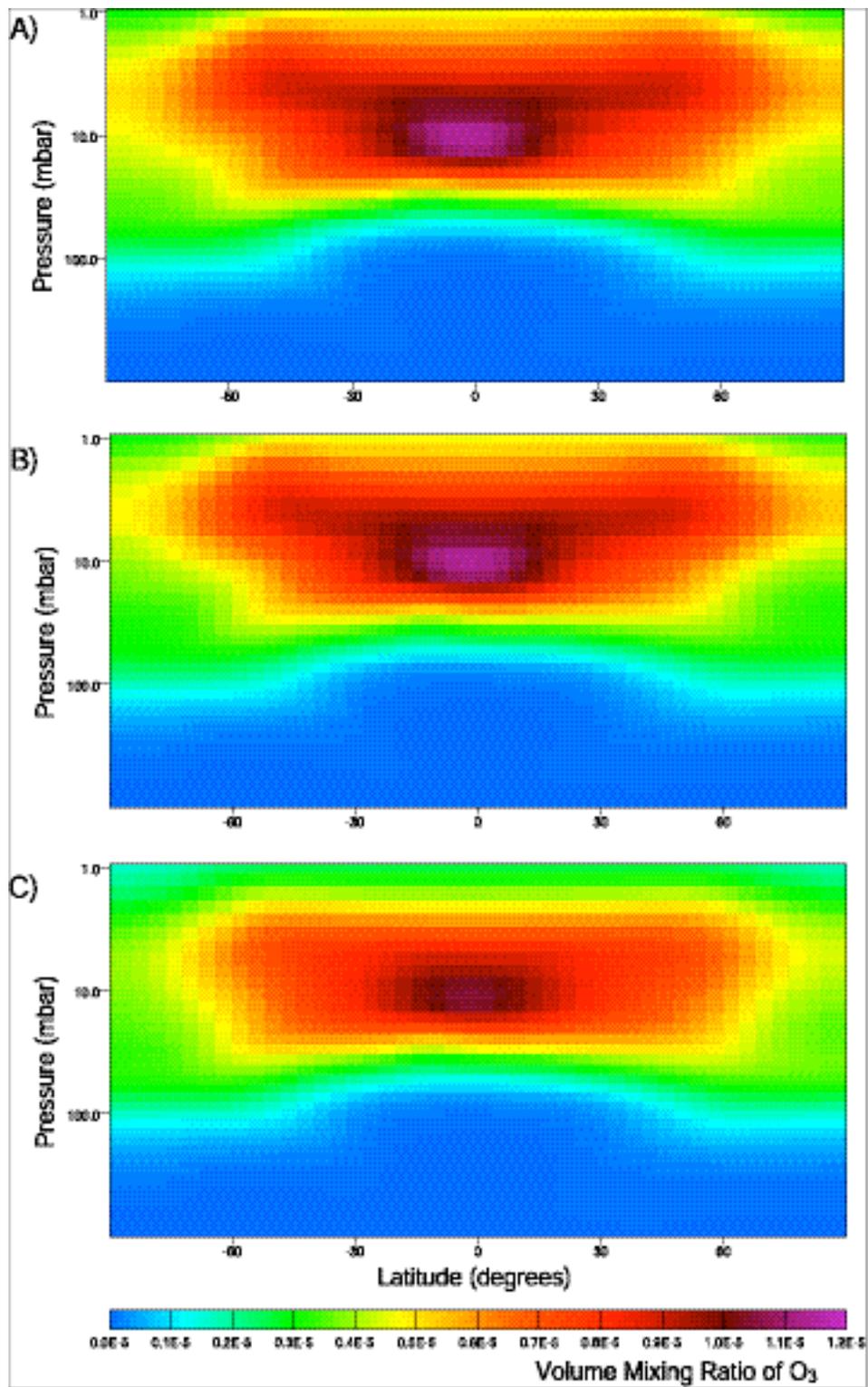
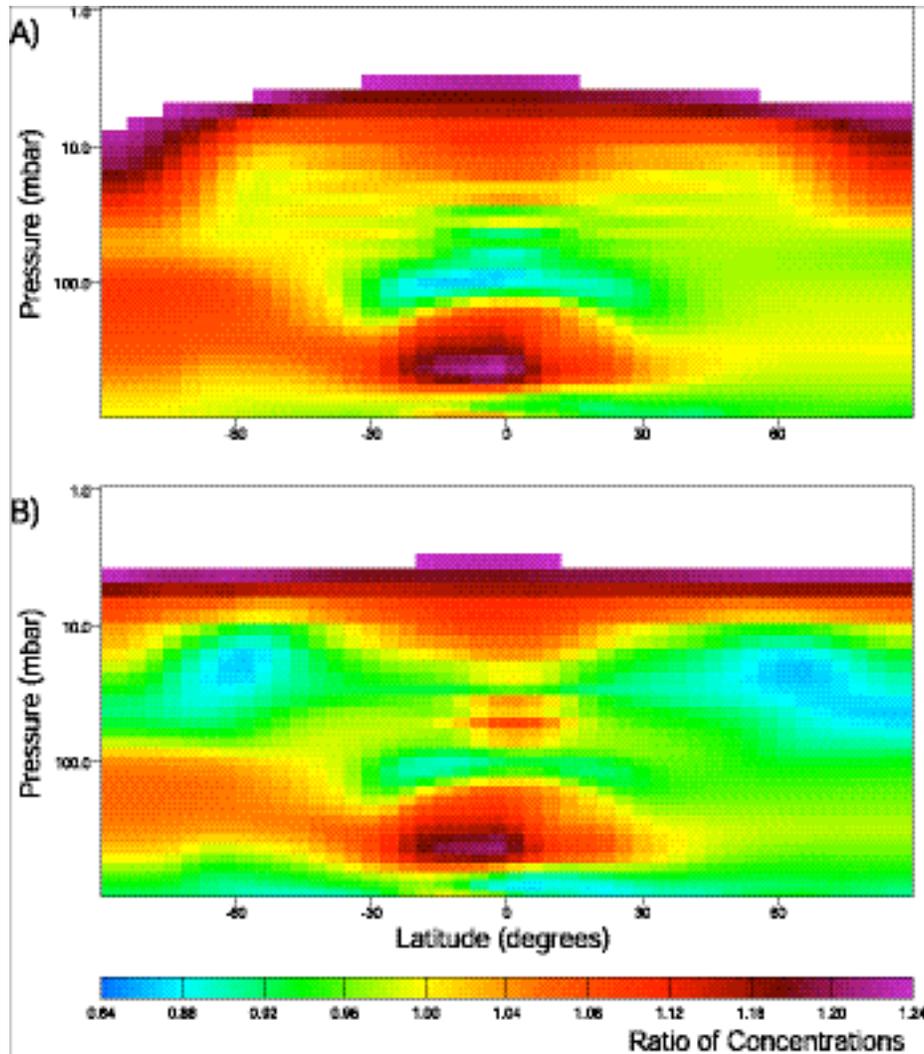


Fig. 32. Volume mixing ratio of ozone in the tropopause region for simulations A, B, and C.

The morphology of the ozone distribution for each of the small mechanism runs (Fig. 32) is reasonable throughout the troposphere and stratosphere. We quantified the comparison using the ratio of zonal mean ozone for each of the small mechanisms to the full mechanism (Fig. 33). The concentration of ozone is now within a factor of 20% throughout the troposphere and stratosphere (as opposed to a factor of 2 previously), and is even closer in the critical tropopause region.

Overall, the compact mechanism using the ozone climatology for photolysis gives a slightly better fit to reality, but the compact mechanism using its own ozone still does a good job, and has the advantage that it will respond to altered climates more consistently.



**Fig. 33. Ratio of zonal mean ozone in July for small chemistry runs to full chemistry run (i.e., A/C and B/C). Note that the scale on these plots is considerably better than in our previous report, where the compact mechanism only agreed with the full mechanism within a factor of 2 in the troposphere and stratosphere.**

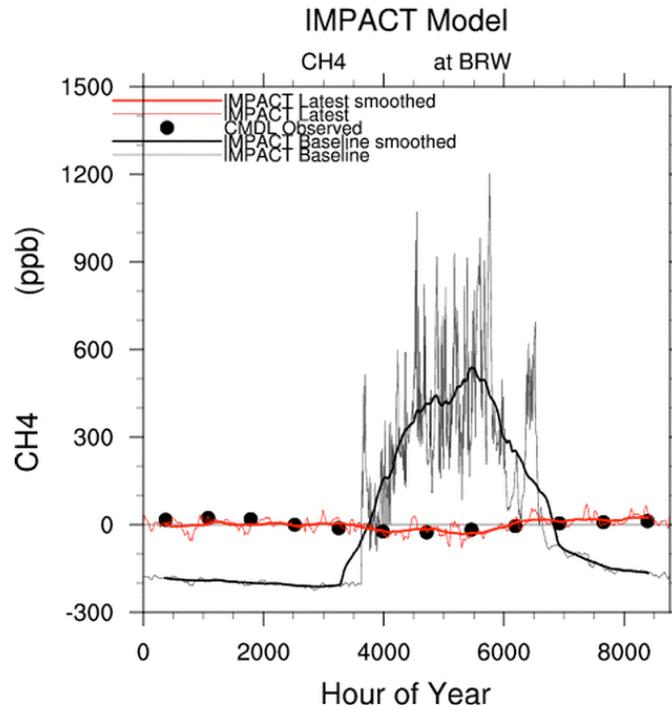
### 9.3 SOURCES AND SINKS OF ATMOSPHERIC METHANE (TAYLOR, CAMERON-SMITH)

Atmospheric methane is the second most important greenhouse gas contributing to anthropogenic climate change. Increasing atmospheric methane concentrations affect the chemistry of the troposphere and stratosphere. As a first step towards the eventual development of interactive methane fluxes, we are currently developing a comprehensive set of source and sink fluxes suitable for inclusion into CCSM based on past research (Taylor et al., 1991). We are currently working on combining previously developed estimates of the sources and sinks of atmospheric methane with more recently derived estimates of atmospheric methane included as part of publicly available data bases. Code will eventually need to be developed to read this data into CCSM and incorporate the fluxes into the atmospheric chemistry code. We will be performing continuing analyses of the distributions and fluxes of methane and carbon monoxide, and their role in influencing the distribution of ozone in the troposphere and stratosphere, as the chemistry solver and chemical mechanism are developed and incorporated into CCSM.

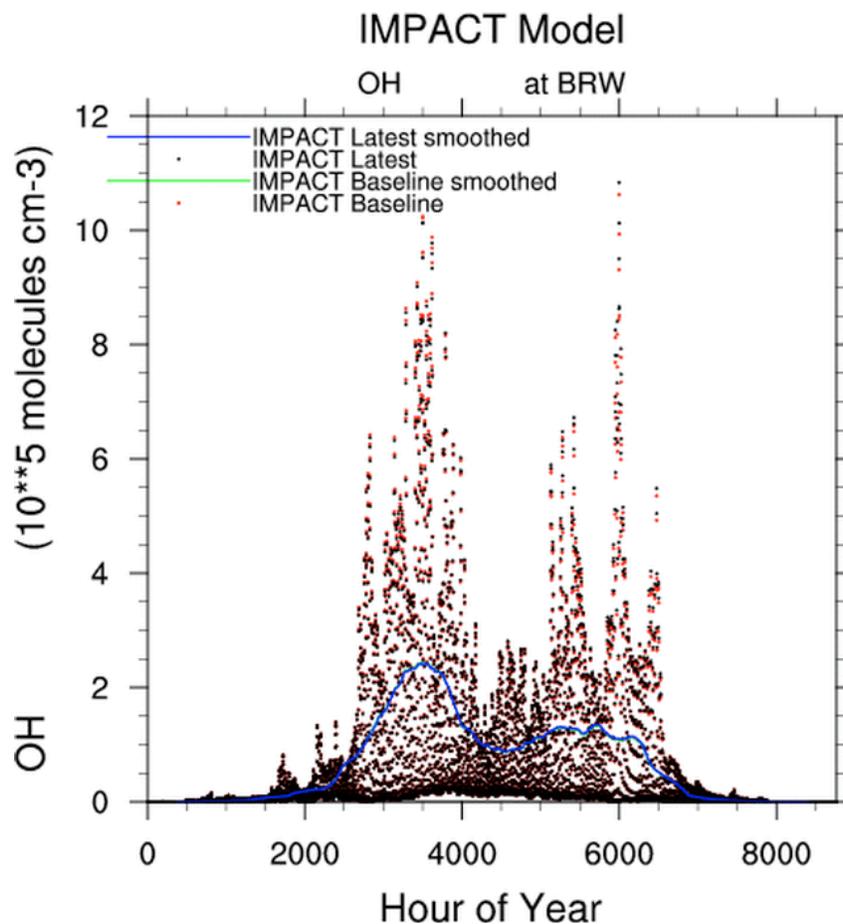
We have completed a comprehensive set of baseline IMPACT model output data for analysis. We have recently completed a new set of baseline runs with modified initial methane concentrations reflecting the observed methane concentration for the mid 1990's. Based on these model runs we have been performing a series of runs aimed at calibrating the methane fluxes in order to produce a growth rate in methane concentration comparable to that observed during the 1990's. These simulations are performed with a state-of-the-art combined troposphere-stratosphere chemical mechanism (TS2, Rotman, et al., 2003). This analysis provides a baseline case for future analyses as we develop the compact mechanism (TS4) and ensure that we do not induce significant model artifacts associated with the compact chemical mechanism. We have nearly completed performing the analysis of the off-line model simulations using the LLNL IMPACT model and are planning to publish the results of our work to date. We are currently porting a version of the WACCM model, as provided by NCAR, to the IBM computers at ORNL and the Jazz Linux cluster at ANL to which we will incorporate our methane fluxes. The results of our work to date are available on the web site located at [http://www-climate.mcs.anl.gov/proj/climate/public\\_html/climate-SciDAC.html](http://www-climate.mcs.anl.gov/proj/climate/public_html/climate-SciDAC.html)

The results under the [CH<sub>4</sub>] tag examine a comparison between the original methane emissions included in the IMPACT model, the new methane emissions data developed as part of the SciDAC project, and Climate Monitoring & Diagnostics Laboratory (CMDL) observations. The new emission fields produce a substantial improvement in comparison with CH<sub>4</sub> measurements made at CMDL monitoring sites, particularly in the Northern Hemisphere. Figure 34 illustrates the improvement in predicted methane concentrations observed at Barrow, Alaska. We have also investigated the effect of changed methane emissions on OH concentrations (see the [OH] tag at the web site above). Figure 35 illustrates a comparison of OH concentrations, again at Barrow Alaska. These results reveal that the changes in methane concentration shown in Fig. 34 are primarily due to changes in methane emissions rather than feedbacks with OH concentration.

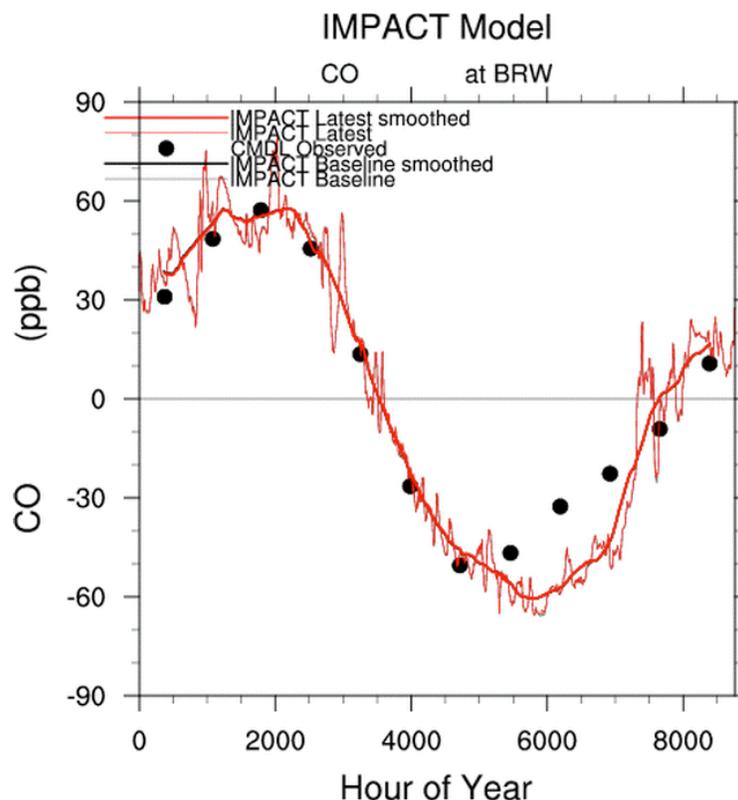
Figure 36 presents a comparison of the seasonal cycle in carbon monoxide (CO) concentrations derived from the IMPACT model obtained using the two methane emissions estimates along with CO observations obtained by CMDL. Changes in methane emissions can affect CO concentrations by changing the rate of production of CO from the oxidation of methane and via changes in OH that alter the rate of oxidation of CO. Figure 36 shows that carbon monoxide concentrations produced by IMPACT are nearly identical for the two methane emissions fields. This result is consistent with the small difference observed in hydroxyl radical concentrations generated by the IMPACT model, as shown in Figure 35.



**Fig. 34. Comparison of deviations (from mean) of methane concentrations derived from the IMPACT model obtained using the original methane emissions (baseline) and the methane emissions developed as part of the SciDAC project (latest). The latest methane emissions included in the IMPACT model produce methane concentrations that more closely match seasonal variations in measured concentrations and show much lower variability.**



**Fig. 35. Comparison of OH concentrations derived from the IMPACT model obtained using the original methane emissions (baseline) and the methane emissions developed as part of the SciDAC project (latest). OH concentrations show only small changes, mostly at high OH values, so we can conclude that the changes in methane concentration shown in Figure 2 are primarily due to changes in methane emissions rather than feedbacks with OH concentration.**



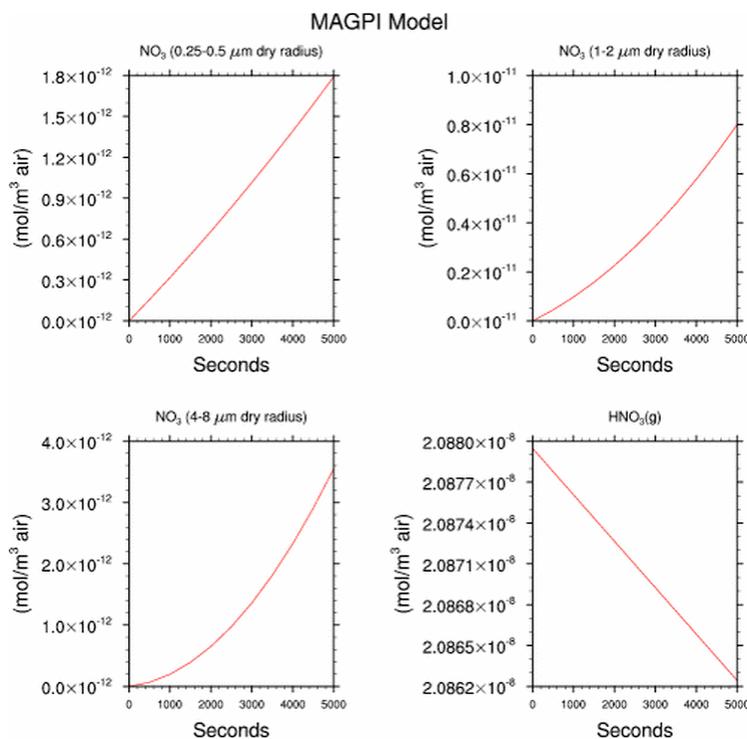
**Fig. 36. Comparison of carbon monoxide concentrations derived from the IMPACT model obtained using the original methane emissions (baseline) in comparison with the carbon monoxide concentrations obtained using the new methane emissions. Carbon monoxide concentrations are nearly identical.**

#### 9.4 MARINE AEROSOL AND GAS PHASE INTERACTIONS (ERICKSON, TAYLOR)

On the marine aerosol and gas phase interactions MAGPI code (Erickson et al., 1999), an initial code redesign included making the code FORTRAN 90 compliant, breaking the code into subroutines representing the functionality of the code, adding Protex headers and reformatting the code consistent with the NCAR documentation requirements. We have recently completed a major modification to this code by adding the capability to use a GEAR ODE solver, consistent with the solvers included in WACCM. The GEAR method is better suited for long simulations with CCSM. This new code base is a needed first step in the transition of the MAGPI model into CCSM and is nearing completion. The next step will be to integrate this new MAGPI code into WACCM.

We have also completed a suite of initial test runs with the new code and we are analyzing the output of these runs. We have also developed a new analysis code for this purpose. The results of our work to date are located at [http://www-climate.mcs.anl.gov/proj/climate/public\\_html/climate-SciDAC.html](http://www-climate.mcs.anl.gov/proj/climate/public_html/climate-SciDAC.html) under the MAGPI tag.

Results are consistent with the original MAGPI code. Figure 37 shows the output of the MAGPI model for the nitrogen species, both in the gas phase and in the aqueous phase on the aerosol particle as a function of time.

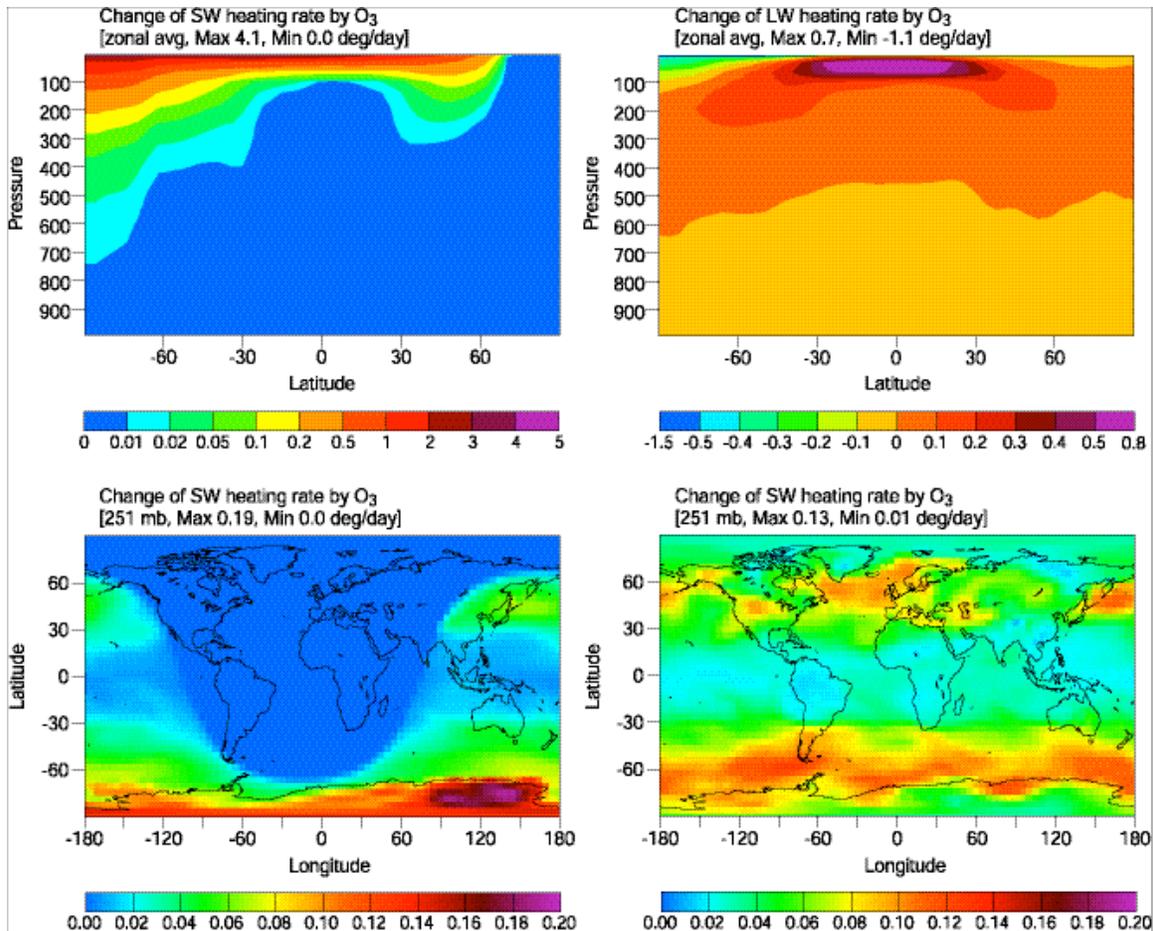


**Fig. 37. Variation in the concentration of nitrogen species in the MAGPI model in both the gas and aqueous phases as a function of time.**

### 9.5 MODEL VALIDATION (CAMERON-SMITH, LAMARQUE, TAYLOR)

We are validating the model results by comparing predicted concentrations with *in situ* observations and the original models that have already been validated (IMPACT, MOZART, and MAGPI). Because the direct coupling from chemistry to the atmospheric model is through radiation, we also need to check that the small mechanism produces heating rates that are comparable to the full mechanism. To this end we have implemented short-wave and long-wave radiation packages into IMPACT. Preliminary results for the heating rate produced by ozone are shown in Fig. 38.

We also plan to analyze the response of the atmospheric model (CAM2) to simulations with and without our additional models using the standard experimental protocol of the AMIP- (AMIP simulations are constrained by observed monthly mean sea-surface temperatures and sea-ice, starting in 1979 and run to near-present). Extensive diagnostic tests will be performed on these runs using diagnostic tools developed by the DOE PCMDI, and will be done in collaboration with Peter Gleckler at PCMDI.



**Fig. 38. Preliminary plot of heating rate due to ozone in the short-wave (0.175 - 4 microns) and long-wave (longward of 4 microns) for midnight GMT, January 1. The upper plots are zonal mean heating rates. The lower plots are on the 251 mbar surface.**

*Is this rate of progress adequate to meet the objectives within the 5 year period?*

Leap-frogging the tropospheric-only chemical model means that we are ahead of our target for our atmospheric chemistry objectives, although there is plenty of work left to do validating the atmospheric chemistry.

The work involved in the CCSM aerosol goals listed under Objectives (above) is far beyond the scope of this SciDAC project. We are therefore in discussion with Bill Collins (Chair of SSC committee) to identify the most useful role we can play under SciDAC for the duration of this project.

*What objectives have been completed?*

We have completed the addition of the MOZART chemical code and combined stratosphere-troposphere mechanism to CCSM. A run of 20 years has been completed and evaluation is in progress. We have also developed a fast compact mechanism in the IMPACT model and ported it to the new CCSM chemistry mechanism format. This code is currently being tested in CCSM.

The new methane emission database has been constructed, and is currently being refined in the IMPACT model to ensure it reproduces observed trends.

The MAGPI code has been made compliant with CCSM standards and a GEAR ODE solver has been incorporated.

### *Plans*

In line with our original plan, our priorities for atmospheric chemistry are the completion, inclusion into CCSM, and validation of the two atmospheric chemistry mechanisms, the methane emission data set, and the MAGPI model.

Also in line with our original plan, we will increase our efforts on implementing aerosols into the CCSM. The exact role we will play under SciDAC, in terms of how we will collaborate with NCAR and which tasks we will complete by the end of this project, is still under discussion with NCAR and the CCSM project. The topics under consideration include: addition of incompletely implemented aerosol species, aerosol microphysics, the 1<sup>st</sup> and 2<sup>nd</sup> indirect effects on liquid clouds, and parameterizing the longwave effects of soil dust and sea salt (see Objectives section above for details).

We will validate each contribution to CCSM through comparison of model species concentrations with *in situ* and satellite observations, and compare the response of the atmospheric model (CAM2) by performing AMIP-type simulations and extensive diagnostic tests developed by PCMDI (see Objectives section above for details).

We will collaborate with the following groups:

1. NCAR WACCM: implementing atmospheric chemistry.
2. NCAR (ACD and CGD: Collins, Rasch, Tie): implementing atmospheric aerosols into CCSM.
3. DOE PCMDI (Peter Gleckler): testing and validating the effect of aerosols and chemistry on the atmospheric model through AMIP style simulations.
4. Ocean biogeochemistry portion of this SciDAC project: to improve the computational structure of MAGPI (a marine aerosol and gas-phase interactions code developed by David Erickson at ORNL); to use DMS generated by the ocean biogeochemical model in the atmospheric chemistry and aerosol code; and to provide aeolian dust output to the ocean biogeochemistry model for iron fertilization.

## **10.4 BIOGEOCHEMISTRY DIAGNOSTICS (K. CALDEIRA, S. DONEY)**

### *Background*

Ocean biogeochemistry is important if we are to model climate/carbon-cycle feedbacks and better understand the consequences of climate and chemical changes on the marine environment. NCAR is leading an effort to develop a marine biogeochemistry model for use in CCSM. It is necessary to evaluate this model in the light of observations, both to understand the reliability of this model and to help point to ways in which the model could be improved.

## Objectives

Initially, we had proposed to help NCAR develop aspects of their biogeochemistry model, specifically, the representation of deep-ocean processes and aspects of some elemental cycles, as well as to help with diagnostics for the ocean biogeochemistry component of CCSM.

In conversation with Scott Doney, at that time leader of NCAR's ocean biogeochemistry modeling effort, it was decided that LLNL's effort in this area could most usefully play a role in the SciDAC-CCSM collaboration by developing diagnostics for the evaluation of marine biogeochemical simulations and apply those diagnostics to the biogeochemical results of CCSM.

Our project will contribute greatly to meeting NCAR and CCSM objectives. The primary goal of this effort is to develop a system wherein NCAR (and other institutions) can quantitatively compare their biogeochemical model results with a wide range of observations. This comparison will be made in an open way that is transparent and understandable to the entire community, and thereby facilitate more rapid improvement of the biogeochemistry component of CCSM.

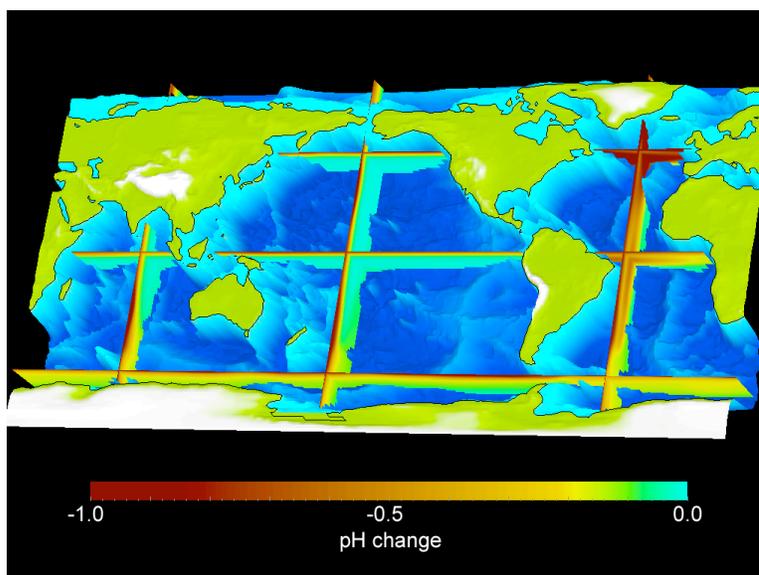
## Progress

Under SCIDAC funding,

- We have developed tools to apply a single analysis to all OCMIP models at once on all OCMIP grids including the POP grid. (Fig 43)
- We can now plot all OCMIP models at once on all OCMIP grids including the POP grid.
- We have developed several biogeochemically-oriented diagnostics of model performance, and tools for handling data and calculating commonly needed quantities (see Fig 42).
- We have begun development of the production automation system — the application framework that will automatically process model results and produce an analysis document.

We have met with our colleagues who are developing diagnostics for European coupled modeling efforts, and who are coordinating OCMIP3. As a result of these meetings, diagnostic capabilities developed in Europe can be incorporated into this SCIDAC effort. Furthermore, if successful, the tools developed under this SCIDAC funded work will contribute to the analysis of OCMIP3 results.

**Fig. 42. Ocean pH changes computed for a model simulation for a business as usual scenario. These pH changes were calculated using diagnostic tools developed in this project.**



Our current level is adequate to develop a useful ocean biogeochemistry diagnostic framework that can be applied to

CCSM within the 5 year period. With a ramp up of funds we could expand this effort, as well as meet our originally proposed objectives of developing, an improved, more mechanistic representation of remineralization in the deep ocean and recycling of trace nutrients in the upper ocean.

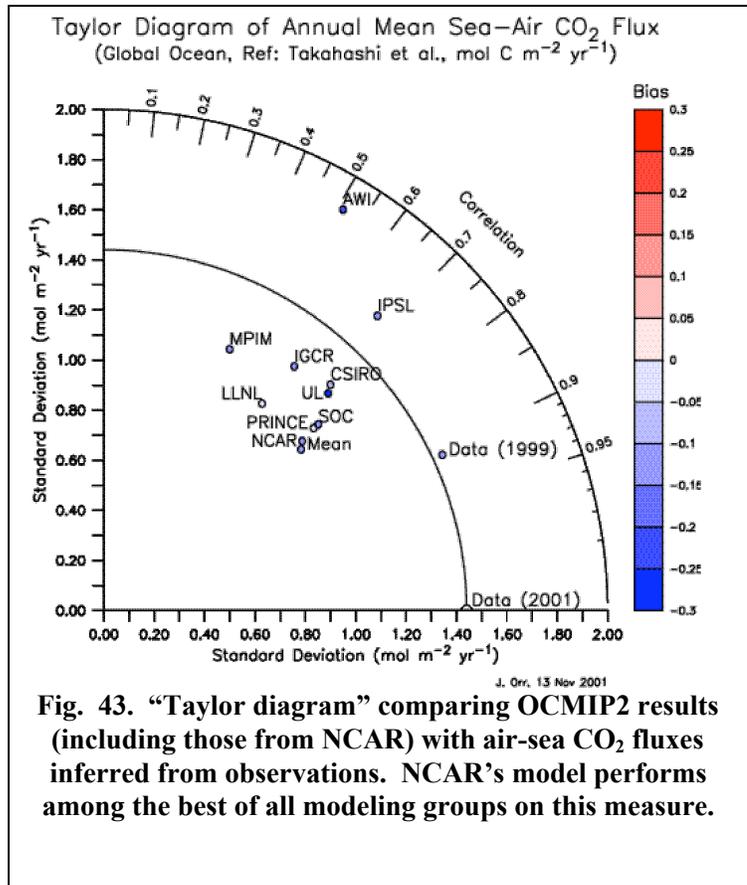
We have completed tasks listed above and we are on schedule to have an up-and-running ocean biogeochemistry diagnostic system suitable for use with CCSM.

*Plans*

The main priority is to get an ocean biogeochemistry diagnostic system suitable for use with CCSM up and running on a server.

The next priority is to begin using this system to diagnose CCSM results, and through an iterative process, add additional useful diagnostics to the system.

We need to coordinate with those running the CCSM biogeochemistry model so that we can use their model output in development of the diagnostics system. Our current testing regime includes analysis of NCAR’s submission to the Ocean Carbon Model Intercomparison Project. The system developed under this project is coordinated with OCMIP efforts and a NASA funded project to compare satellite observations with model predictions of ocean color.



**Fig. 43. “Taylor diagram” comparing OCMIP2 results (including those from NCAR) with air-sea CO<sub>2</sub> fluxes inferred from observations. NCAR’s model performs among the best of all modeling groups on this measure.**

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