OVERVIEW OF THE CLIMATE IMPACT ON REGIONAL AIR QUALITY (CIRAQ) PROJECT

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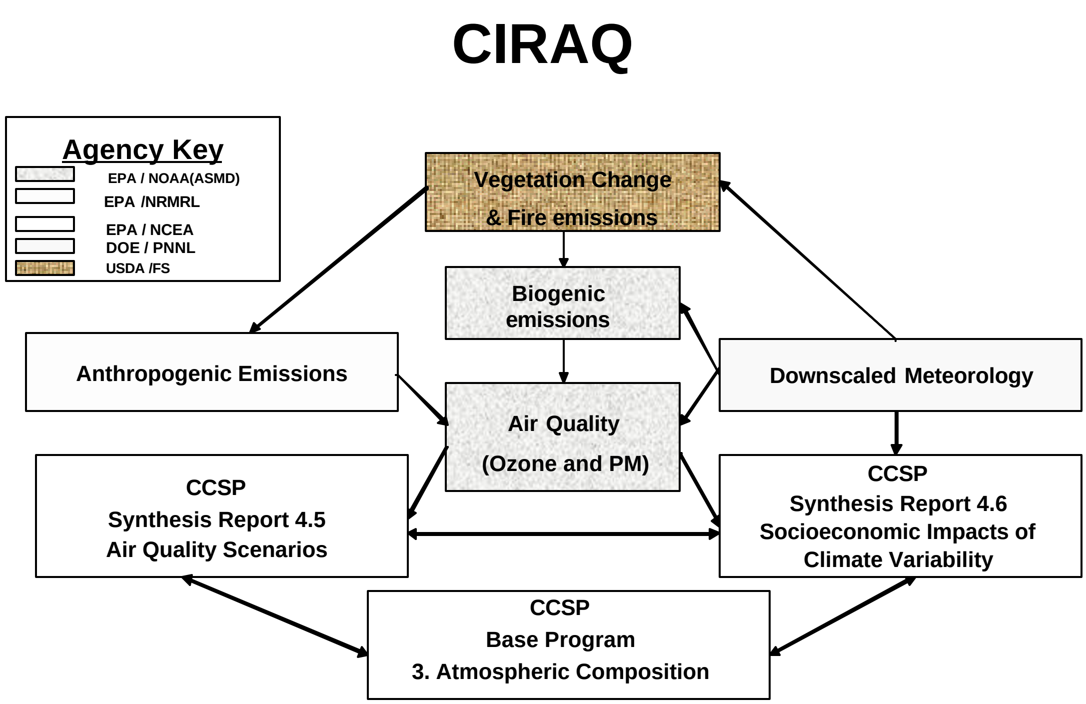
1.0 INTRODUCTION

Predicted changes in the global climate over the next hundred years and more could create new weather patterns and associated changes in land use, source emissions, and tropospheric air quality. The U.S. EPA Climate Impact on Regional Air Quality (CIRAQ) project, illustrated below, examines present-day and future (circa. 2050) global climate scenarios as they might affect regional and urban tropospheric air quality in North America. This work supports the U.S.EPA Global Change Research Program (GCRP) as well as contributes to U.S. Climate Change Research Program (CCSP) synthesis reports dealing with atmospheric composition (CCSP, 2003). Primary drivers of future air quality are climate variability, climate change and emissions. CIRAQ addresses these drivers by first isolating air quality response to future climate alone (Phase I). CIRAQ Phase I employs a Global Climate Model (GCM) to generate downscaled regional climate conditions under present and future climate scenarios. These regional climate modeling scenarios will then be used to drive the Community Multi-Scale Air Quality (CMAQ) model. To isolate the effects from potential climate change, emissions will remain constant for the Phase I simulations, except for changes that are a response to climate factors. More detailed model specifications for these simulations are provided in following sections. CIRAQ Phase II will revisit these



air quality scenarios using an alternative emission inventory that includes some estimate of future economic, population and technological change in the continental U.S. and, perhaps, expand the analysis to include additional future climate scenarios.

CIRAQ represents a first attempt to perform a detailed analysis of air quality response to climate variability and change across the full continental U.S. domain at a regional scale resolution. As such, it introduces several new challenges for CMAQ model application, analysis and interpretation. This study will require generation of multi-year model simulations and coordination with, and integration of data and model results from a variety of new sources. For example, Global Chemical Transport (GCT) model output must be linked with the regional-scale meteorological and air quality models to account for global scale climate forcing. Also, dynamic biogeographic models and future emission projection systems such as the Economic Growth and Analysis System (EGAS, E.H. Pechan & Assoc., Inc., 2001) and MOBILE6 (Office of Transportation and Air Quality, 2002) must all be integrated to develop future air quality emission scenarios that go beyond using coarse emission adjustment factors that were intended for global scale climate modeling. In addition to these technical issues, model uncertainties and biases on the global and regional scales suggest that the CIRAQ simulations should be considered an investigative model sensitivity study and that additional comparisons across different models would increase our confidence in the results. These and related research issues are being addressed by the EPA Global Change Research Program through CIRAQ, through related projects in other ORD Laboratories and EPA Program Offices (e.g. NRMRL, OAQPS), through Science to Achieve Results (STAR) research grants and through collaboration with other Federal Agencies (e.g., DOE, USDA/FS).

2.0 CIRAQ APPLICATION ELEMENTS

The CIRAQ project is made up of several distinct application elements - all building towards an integrated, physically consistent description of future air quality status and change. Primary Phase I elements include 1) development of present-day and future regional climate scenarios (RCM's), 2) development of present and future climate driven emission scenarios, and 3) execution, diagnosis and interpretation of CMAQ results.

2.1 *Regional Climate Scenarios*

Development of climate scenarios for regional scale air quality applications presents new challenges for the climate change research community. First, even relatively coarse national-scale policy-relevant air quality studies require information at horizontal resolutions of approximately 36km × 36km, and the vertical resolution of the meteorological fields must resolves boundary layer processes. GCM simulations have horizontal resolutions of a few degrees latitude and longitude typically and relatively coarse vertical layering as compared to mesoscale meteorological models; therefore, regional scale air quality models require a higher spatial resolution than GCMs provide.

These requirements are addressed through the use of the Fifth Generation Pennsylvania State University/National Center for Atmospheric Research Mesoscale Meteorological Model (MM5; Grell et al., 1994) to generate physically consistent downscaled regional climate scenarios from coarse resolution GCM data. Downscaling of the NASA Global Institute for Space Studies (GISS) version II', GCM (Rind and Lerner, 1996; Rind et al., 1999) has been performed for CIRAQ through a partnership with the DOE Pacific Northwest National Laboratory (Dr. Ruby Leung). The overall goal of this type of downscaling is to make maximum use of GCM information, and so MM5 parameterization schemes were selected to maintain the large-scale GCM climate patterns and variability while adding the finer scale detail needed to support CMAQ applications. MM5 configuration for CIRAQ includes 23 vertical layers, the medium range forecast model (MRF) planetary boundary layer scheme, the Grell cumulus cloud parameterization scheme, rapid radiative transfer model (RRTM) and a mixed phase microphysics model, Reisner1, without graupel. Since these simulations are driven by GCM information rather than assimilated observation or reanalysis, they do not necessarily reproduce day-to-day and exact year-to-year observed variations but rather, represents time periods under the representative climatological conditions. In addition, without the assimilation of observed data, model biases in the

GCM will be introduced into the RCM scenarios. Thus, careful evaluation that is appropriate to the climatological nature of the scenarios is essential to identify and to better understand climatological biases that could impact CMAQ model performance.

Once complete, the downscaled MM5 scenarios are carefully quality controlled and processed through the Meteorology-Chemistry Interface Processor (MCIP) version 2.2. It is the MCIP scenarios that are evaluated and compared to observation to facilitate later CMAQ diagnosis as well as climate scenario study. MCIP scenario analysis takes three forms; 1) analysis to screen model output to check for sensible mean and variability results, 2) timeseries analysis to characterize the seasonal and interannual components relevant to specific air quality-related meteorological conditions and 3) spatial analysis to study large scale dominant patterns as well as unusual or extreme patterns of atmospheric transport relevant to specific air quality-related meteorological conditions.

2.2 *Emissions Scenarios*

Baseline (current) and future emission scenarios specifying the Statewide (California) Air Pollution Research Center (SAPRC; Carter, 2000) chemical mechanism with speciation profiles for criteria pollutants are required for the CIRAQ analysis. Inventory-based emissions derive from the most recent 2001 modeling inventory (referred to as 01ad) prepared for the Office of Air Quality Planning and Standards (ref.). Plume rise is computed for all possible point sources. Major point sources, such as Electric Generating Unit stacks, are not separately defined. Instead, annual electrical generating unit values are disaggregated with temporal profiles.

Some meteorology-dependent emission data (i.e. not from an inventory) are modeled using the same hourly meteorological data used by CMAQ. These include biogenic emissions (modeled by the Biogenic Emission Inventory System, Version 3.12; Pierce, et al., 1998; Pierce et al., 2002) and on-road mobile source emissions modeled by the U.S. EPA MOBILE6 mobile source emission model. The Sparse Matrix Operator Kernel Emission (SMOKE; Carolina Environmental Programs, 2003) model will be used to prepare current and 2050 emission inventories for use with planned CMAQ model runs.

CIRAQ Phase II captures the direct and indirect effects of changes of biogenic and anthropogenic emissions by including projections of emissions to the year 2050. In order to create a range of scenarios of projected emission values, many natural, economic, and technological factors must be considered. The methodologies to be used could include (1) modeling of future electric generation and transportation technologies and their emission implications, using the MARKAL model (an energy systems optimization modeling framework; Seebregts, et al., 2001; Fishbone et al., 1983) and updates to the MOBILE6 on-road motor vehicle emission model; (2) the projection of emissions based on economic growth factors by emission source category and geographic region, possibly using an updated version of EGAS; (3) determination of the most likely land use change scenarios for North America, including urban-rural population shifts, principal road network changes, and commercial development patterns; and (4) spatial and species composition changes in vegetation land cover, which in turn affect biogenic emissions.

2.3 *Generation of the Air Quality Scenarios*

The air quality modeling scenarios will be generated using the USEPA Community Multiscale Air Quality (CMAQ) model, version 4.4 with SAPRC chemical mechanisms. In agreement with the regional climate modeling scenarios, the horizontal domain will cover the contiguous United States at a 36km x 36 km grid resolution. Using CMAQ's MCIP version 2.2 processor, the vertical resolution of the regional climate simulations have been collapsed to 14 sigma layers with the lowest layer being 36m thick and the upper bound being 100mb.

To provide initial and boundary conditions for these CMAQ simulations, a CTM was used that is driven by the same GCM providing boundary conditions to MM5 for the RCM simulations described in Section 2.1, i.e., GISS II'. Online chemistry has been integrated into GISS II' to provide ozone and tracer predictions (Mickley et al., 1999). The resolution for these model predictions is quite coarse at 4° x 5°. Evaluation of a related global CTM at this spatial scale has shown spatial prediction patterns that were quite good but local maximas that were compromised (Fiore et al., 2003). Since we are using the global CTM predictions as background monthly-average values, the coarse resolution should be sufficient. An obvious advantage is that these GCM-based chemical predictions provide chemical boundary conditions under current and future climate change scenario forcing.

When comparing current to future modeling simulations, it is important that we consider interannual variability as well as climate trends. Five annual simulations will be performed for the current and future (2050) time periods. Again, since the model simulations are based on a GCM, these will not represent the specific years but rather five years that are representative of the climatological conditions. CMAQ analyses will attempt to identify climate-related signals in current versus future air quality predictions. Evaluation of the current time period will also be performed with approaches that recognize the climatological nature of the simulations. It is anticipated that these Phase I simulations and associated analyses will be complete by the end of 2006 for inclusion in the EPA GCRP 2007 report.

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DISCLAIMER:

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