# Air Quality – Climate Interactions
# A NARSTO Role
# April 12, 2005

**Background**
At the April 2004 NARSTO Executive Assembly, Dan Albritton, Peter Lunn, Joel Scheraga, Jake Hales, and Jeff West presented a paper entitled "Air Quality – Climate Interactions: Research Needs and Implications for Future NARSTO Activities." The paper reviewed features of the air quality and climate changes research agenda that the two issues held in common. It discussed the implications of these common features to NARSTO's traditional activities, and it suggested some possible activities NARSTO could undertake that would make positive contributions to advancing the science in both arenas. The Executive Assembly agreed that there are a number of common scientific and technical problems associated with air-quality management and climate change mitigation and adaptation that fall within NARSTO's scope of expertise. The Assembly agreed that addressing these common problems fell within NARSTO's charter, and it directed the Management Coordinator to recommend to the Assembly a set of activities NARSTO might undertake to address the air quality – climate change problem.

**Common Problems and Opportunities in Air-Quality and Climate Science**
At the most basic level the issues of air quality and anthropogenic climate change are different manifestations of the same driving force – modification of the chemical composition of the atmosphere due to human activities. As the magnitude of this modification has increased, the spatial scale of its impacts has steadily grown from local, to regional, to global. As will be discussed in more detail below, there are a number of scientific and technical factors that link these two issues and argue strongly for a "one atmosphere" approach to dealing with them. Among these commonalities are the complexity of the processes that link emissions to effects, the inherent uncertainties in predicting the consequences of these processes, several emissions and processes that are common to both phenomena and are therefore linked, and the fact that policy actions taken to address one of these problems might have intended or unintended consequences for the other.

There are, however, three fundamental differences between these two issues:
1) The principal emissions responsible for air quality problems generally result from process inefficiencies at the sources or from fuel contaminants. They can be reduced or eliminated by process improvements or by control devices that treat emissions before

they are released to the environment. In the case of climate change, emission of the most important greenhouse gas, $CO_2$, is an inherent consequence of the combustion of fossil fuels. Removing and sequestering these emissions are a much more complicated and costly endeavor.

2) Emissions responsible for most air-quality related problems have relatively short residence times in the atmosphere. Consequently, environmental improvements associated with emission reductions should occur relatively rapidly – within years or, at most, decades. Several greenhouse gases, on the other hand, have much longer residence times – several centuries in the case of $CO_2$. Long residence times and the thermal inertia of the coupled ocean/atmosphere system mean a considerable delay between action and response. Unlike air quality, people paying the costs of greenhouse gas reductions may not live to see the benefits.

3) In the case of air-quality management, there are probably emission levels below which there are no statistically significant impacts on human or ecosystem health. With respect long-lived greenhouse gases, however, any emissions that exceed natural rates of removal will result in increases in atmospheric concentrations. Thus, stabilizing the atmospheric concentration of a long-lived greenhouse gas such as $CO_2$ requires that the net emissions from fossil-fuel sources must ultimately go to zero.[1]

In spite of these differences, however, there remain strong scientific, economic, and policy reasons to forge a coordinated approach to dealing with both issues. From the science perspective, the more significant intersections occur in the following subject areas:

Emissions

Except for $N_2O$ and methane (where long-term increases in global concentrations could affect the oxidative capacity of the atmosphere) emissions of the principal greenhouse gases have little consequence for tropospheric air quality. The exceptions are emissions that affect the concentrations of atmospheric aerosols or particulate matter (PM). The direct and indirect (i.e., cloud-related) effects of atmospheric aerosols on the Earth's radiative energy budget remain the largest climate-forcing uncertainties (IPCC, 2001). The principal sources of these aerosols are primary emissions of fine PM due to fossil fuel combustion, biomass burning, soil dust and sea salt; as well as the formation of secondary aerosols by chemical reactions in the atmosphere. The sources of these secondary aerosols include the same emissions of interest in air-quality management: $NO_x$, $NH_3$, $SO_2$, and certain classes of volatile organic compounds (VOCs).

Dealing with the climate issue requires consideration of long-term trends in emissions. These trends must account for changing technologies, as well as trends in population and economic development. For climate, we must know emission trends globally. But there

[1] This is not the same thing as saying that the use of fossil fuels must be eliminated. Fossil fuels can and will be used for the foreseeable future. Fossil fuels can be part of a strategy for stabilizing $CO_2$ concentrations if there is a compensatory amount of $CO_2$ capture and permanent sequestration. Transition to zero net emissions can also take place over considerable time. Wigley et al. (1996), for example, show one strategy for capping $CO_2$ concentrations at twice the pre-industrial value that has $CO_2$ emissions peaking in the late decades of this century and declining to zero over the following 100 years or so.

is a definite air-quality management feedback from this knowledge. With growing global emissions, long-range transport and changes in background global chemistry will be increasingly important to local, regional and continental air quality background concentrations. Consequently, both air-quality management and climate-change research and policy analysis require self consistent methodologies for obtaining long-term emission scenarios for greenhouse gases, $NO_x$, $NH_3$, $SO_2$, primary particulate emissions, and VOCs. These methodologies must provide self-consistent emission estimates from the global down to at least the regional scale.

From a policy perspective, joint consideration of emission reduction strategies from both an air quality and climate perspective can be more cost-effective in the long run and facilitate development of true "win-win" strategies. For example, pursuing such a one-atmosphere approach could help us avoid taking short-term actions designed to ameliorate near-term air quality problems that could complicate or even preclude attractive long-term actions that might be needed to deal with climate change.

Atmospheric Process Research

Both air-quality and climate science need improved understanding of the processes that govern the formation, chemical transformation, transport, and removal of particulate matter in the atmosphere. From the air-quality perspective, the driver is the need to know how these processes might affect human and ecosystem exposure to particulate matter. From the point of view of climate science, the need is for a better understanding of the role of aerosols in atmospheric radiative energy transfer. Although the scientific drivers may differ, the atmospheric processes that govern these effects (chemical transformation, removal, etc.) are the same. The scope and complexity of the research needed to advance our knowledge of these processes exceed the available financial and human resources. Consequently, there is considerable advantage to coordinating climate and air-quality aerosol research, and we should look for opportunities to do this whenever possible.

The principal differences between the design and objectives of air-quality and climate process research studies arise when the research questions turn to the interactions between aerosols and clouds. Air-quality related research is interested in cloud and precipitation removal processes, aqueous phase chemistry, and cloud transport and processing of aerosols. Studies focused on climate effects are also interested in these phenomena, but they are more concerned with the so-called indirect effect of aerosols on radiative energy transfer. This effect is probably the most difficult topic to deal with from a process-research standpoint. There are two aspects to the indirect effect. The first is the effect that aerosols might have on cloud droplet (or cloud hydrometeor) size distribution and phase. These properties largely affect cloud optical properties such as albedo. The second aspect is the effect aerosols might have on cloud formation, precipitation efficiency, and lifetimes. Although both of these effects can have significant climate consequences when averaged over a large cloud sample, their importance to the formation, lifecycle, and microphysics of a given cloud are secondary to other meteorological forcing factors. Consequently, it is difficult to sort out indirect effects in short-term field research projects that are typical of most air-quality related field research activities. Obtaining better understanding, as well as testing model simulations, of the indirect effect may require longer duration studies and may require observational facilities that begin to look like monitoring installations.

There are other atmospheric process questions that cross-cut the fields of air-quality and climate science and suggest additional opportunities for research coordination. Numerous opportunities for research coordination are suggested in the research questions outlined in the strategic plan of the U.S. Climate Change Science Program (CCSP, 2003). For example,

<u>CCSP Question 3.1</u>: *What are the climate-relevant chemical, microphysical and optical properties and spatial and temporal distributions of human-caused and naturally occurring aerosols?*

- What are the global sources of particle emissions and their spatial and temporal variability?
- What are the regional and global sources of emissions of aerosol precursor gases?
- What are the optical and microphysical properties of various classes of primary and secondary aerosols and how are these properties affected by atmospheric processing?
- What is the relative importance of secondary organic aerosols and how might this relative importance change as future air-quality control measures are implemented?

<u>CCSP Question 3.2</u>: *What are the atmospheric sources and sinks of greenhouse gases other than $CO_2$ and the implications for the Earth's energy balance?*

- How is the oxidative capacity of the atmosphere changing, and how are North American emissions contributing to this change and to global atmospheric composition?

<u>CCSP Question 3.3</u>: *What are the effects of regional pollution on the global atmosphere and the effects of global climate and chemical change on regional air quality and atmospheric chemical inputs to ecosystems?*

- What are the impacts of climate change and long-range transport of regional air pollution on human health?
- How do primary and secondary pollutants from the world's megacities contribute to global atmospheric composition?
- What are North American "background" levels of air quality and how does long range transport contribute to these levels – that is, what levels of pollution are beyond national or North American control?
- What controls the long-range transport, accumulation, and eventual destruction of persistent organic pollutants or the long-range transport, transformation, and deposition of mercury?

<u>CCSP Question 3.5</u>: *What are the couplings and feedback mechanisms among climate change, air pollution, and ozone layer depletion, and their relationship to the health of humans and ecosystems?*

- How do changes in anthropogenic emissions of $NO_x$, CO, and VOCs affect the abundance of $CH_4$ and $O_3$ on regional and global scales?
- How is air quality affected by changes in climate and weather patterns?
- How do the regional and global radiative forcings of aerosols respond to changes in aerosol precursor gases (e.g., $SO_2$, $NH_3$, and VOCs)?

Other relevant questions from the CCSP strategic plan include:

- How do aerosols affect the radiative properties, lifetimes, and precipitation processes in clouds?
- How might changes in regional air quality, coupled with climate variability and change, affect ecosystems?
- What are the impacts of atmospheric and climatic changes on the health effects associated with ambient air quality and UV radiation?

Effects

From the air quality point of view, one of the most obvious interactions between climate change and air quality is how changes in climate might affect air-quality meteorology in the future. In other words, will changes in climate affect the frequency, duration, and intensity of atmospheric conditions conducive to the formation of poor air quality events? Will conditions favoring poor air quality become more wide-spread?

The U.S. EPA is already conducting studies on how climate change might affect air-quality meteorology for the United States. The methodologies being developed for these studies, as well as the results themselves, should be of interest to Mexico and Canada as well. The principal question attending these studies is how capable current climate models – even coupled global/regional climate models – might be in simulating the kinds of conditions responsible for poor air quality episodes and in estimating their future statistics.

Besides the effects climate change might have on the propensity for poor air-quality episodes, other effects questions that have a significant climate/air-quality connection are pointed out in the CCSP Strategic Plan. They include

- How will the oxidative capacity of the atmosphere change as a result of global-scale emissions, and how might this change affect air-quality management for North America?
- How are global-scale emissions affecting background concentrations of regulated pollutants?
- What is the current and future significance of long-range intercontinental transport of pollutants and pollutant precursors?[2]
- How might these changes affect ecosystems, visibility, and other air-quality affected resources or values?

All of these effects are of interest to NARSTO countries, and they could be subjects for future NARSTO activities.

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[2] Associated with this issue is the long-range transport of aerosols and how this transport might affect local cloud properties and climate.

## Modeling, Simulation, and Forecasting

As interest in climate simulation has become more focused on regional-scale changes and impacts, there has been some convergence in the interests and concerns of air-quality and climate modelers. A coupled climate and global chemistry model must deal with much of the same chemistry as a regional scale air-quality or global aerosol model. And when it comes to the aerosols themselves, the convergence in interests and concerns become nearly complete. At the regional scale, climate and air-quality models, including air-quality forecast models, will share nearly all of the same process-simulation needs. Both kinds of models must deal with primary emissions, secondary aerosol formation, chemical transformation, transport, and aerosol removal processes. However, there will be differences in the aerosol effects emphasized by the different models. A climate model will focus on how aerosols affect radiative energy transfer, cloud optical properties, cloud lifecycle, and precipitation; whereas air-quality models will focus on those aerosol properties important to health or ecosystem impacts.

In spite of these differences in the effects emphasized by the two communities, there are substantial opportunities for collaboration between both modeling camps in terms of improving the treatment of aerosol processes and effects in regional to global models. Much of the uncertainty about the effects of aerosols on climate forcing stems from the crude treatment of aerosol processes in climate models. At the scales of regional-climate and air-quality models, there is considerable potential for collaboration between the air-quality and climate-modeling communities and those engaged in the design, conduct, and analysis of aerosol process studies. At this scale, the models can begin to treat aerosol chemistry and physics in a fairly realistic fashion. Thus, model-simulated aerosol properties and processes should compare with what can be observed and measured in the field. Likewise, advances in process understanding, which might proceed from laboratory experiments, field observations, and even more sophisticated high-resolution modeling, are more easily translated into improved parameterizations at the regional or smaller scale. Subsequently, these parameterizations can inform and improve the kinds of aerosol process parameterizations that must be used by much coarser resolution global models. There is great potential for achieving accelerated scientific progress through joint collaboration among scientists engaged in aerosol process research and modeling in the fields of air-quality and climate science. However, it is important to emphasize that such synergy and knowledge transfer will not occur automatically. It needs to be facilitated and managed.

## Monitoring

The issues of air-quality management and climate change share a need for high-quality, long-term monitoring of atmospheric composition in order to document trends in key atmospheric constituents. The U.S. CCSP Strategic Plan, for example, calls for

a) Continued baseline observations of atmospheric composition (esp., greenhouse gas concentrations) over North America
b) Improved description of the distributions of aerosols and their optical properties
c) Monitoring of the concentrations of tropospheric ozone and selected precursors (e.g., $NO_x$ and VOCs – both natural and anthropogenic)

Although some of the required infrastructure is in place for achieving these objectives, there is need for enhancement. Networks for monitoring climate-related variables will focus on background conditions, but the advantage of coordinating these measurements with air-quality monitoring networks is obvious – especially as air-quality management becomes increasingly a regional to continental-scale problem. Both the air-quality and climate-research communities should cooperate in the design of new and the continued operation and enhancement of old networks that can support the observational needs of both communities. It is also important that both communities consider long-term research observing facilities such as DOE's ARM sites as part of this infrastructure. It would probably be advantageous to both communities to expand ARM-like observing facilities to other locations better suited for observing aerosols and their effects on clouds. Long-term, research-quality observations from surface sites similar in capabilities to the ARM sites or to the new ARM Mobile Facility could be a critical source of data for teasing out and verifying aspects of the indirect effect of aerosols on radiative energy transfer.

Assessments and Synthesis

Over the next several years, the U.S. CCSP is planning a number of synthesis and assessment documents regarding climate change and the interrelationships between climate change and air quality. The role that NARSTO can play in supporting the development of these national synthesis and assessment products, which are being generated by designated government agencies, is probably limited. However, NARSTO could play a role in producing a synthesized assessment of the interrelationships between climate change and future air-quality for the three countries of North America. NARSTO might also consider developing an assessment of the current state of knowledge concerning aerosol chemistry. Such an assessment would complement the radiative transfer and global modeling emphasis of the 2001 IPCC science assessment. Addressing the gas-phase and heterogeneous chemistry of aerosols, as well as the direct effect of aerosols on radiative transfer, is well within the scientific competence of the NARSTO community. Dealing with the indirect effect and with cloud microphysics and chemistry would require NARSTO to add expertise from a different group of scientists.

Any involvement by NARSTO in the development of climate-related assessments could only be undertaken at the invitation of the U.S. CCSP and the IPCC. NARSTO should keep informed on the progress of the CCSP assessment and synthesis activities and be prepared to offer assistance if requested.

**A NARSTO Air-Quality/Climate-Change Action Plan**

As discussed in the previous section, climate change and air quality are linked at a number of technical and policy levels. There is a clear advantage in coordinating scientific activities between the two fields and in examining how current and future policy actions might facilitate or complicate joint management of these environmental problems. The following section proposes to the Executive Assembly several activities that NARSTO might undertake to assist with this coordination for North America. These activities are intended to be consistent with the kinds of activities that NARSTO has proven to be most successful in organizing and implementing. They also need to be considered in light of other new or ongoing activities NARSTO might undertake over the next few years.

1. Analysis of Current Air-Quality and Climate-Research Activities and Plans

This effort, which would be undertaken by the NARSTO Management Coordinator (with some assistance from others), will examine current research plans and concerns in Canada, the United States, and Mexico regarding air-quality and climate change. The focus of this analysis would be on the effects of climate change on air quality, aerosol processes and modeling, and the effects of long-range transport and changing background chemistry on air-quality management in North America. The purpose is to examine both the plans and current execution of the plans. The objective is to summarize how this issue is viewed in the three NARSTO countries, what research is being undertaken to address these interface issues, how this research is being coordinated, and whether or not there appear to be any significant gaps in coverage or emphasis that are not being addressed by current or planned efforts. The analysis would engage private sector interests in the three countries in order to solicit their views and concerns regarding this issue. The product would be a report to the Executive Assembly on the results of the analysis and prioritized suggestions as any role NARSTO might play in improving these research efforts.

2. Regional Aerosol Modeling Workshop and Assessment

As has been discussed in other sections of this whitepaper, representation of aerosol processes and effects remain the largest source of uncertainty in climate modeling. Improving the treatment of aerosol formation, chemical transformation, transport, and removal of particulate matter in local to regional air-quality models as well as hemispheric transport and chemistry models is also a high priority for the air-quality modeling community. With this increased emphasis on atmospheric aerosols, the time is right for an in-depth assessment of current models and their research needs. It has been suggested that NARSTO organize such a workshop. The subject of the workshop would be an assessment of how well current state-of-the-art regional to hemispheric models handle critical aerosol processes and how accurately they treat the effects of aerosols on radiative energy transfer and on cloud properties and processes. Some of the questions that could be addressed by such a workshop include

a. How are aerosols and aerosol/cloud processes represented in the models?
b. How well do model simulations agree?
c. Why are there differences?
d. How do model simulations compare with observations?
e. What approaches show promise for improving aerosol modeling at regional and hemispheric scales?
f. How can collaboration with laboratory and field research be improved in order to expedite the application of observational research to the improvement of models?

The product of the workshop would be a report summarizing the state-of-the-art and suggestions for accelerating model development, evaluation, and improvement. The critical elements for a successful workshop of this type are recruitment of a critical mass of leading modelers and the design of acceptable protocols for implementing the models and comparing them with one another and with observations.

3. Emission Inventory Assessment Follow-Up

Although the NARSTO emission inventory assessment mentions greenhouse gas emissions, its principal focus is on air-quality related emissions. This undertaking would be a small-scale follow-up to the assessment addressing how the findings and recommendations specifically apply to the greenhouse gas inventories of the NARSTO countries. In addition to the principal greenhouse gases, emphasis would be placed on the air-quality related emissions that are significant for climate change. Another point of emphasis would be on methodologies for projecting future greenhouse gas and air-quality related emissions. There are differences in the ways that future emission scenarios are developed. This follow-up assessment would address whether or not we are achieving the goal of providing self-consistent emission estimates from the global to the regional scale.

**References**

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