The New England Air Quality Study

Science to Support Decisionmaking

Draft Science Plan

October 2001

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Background

New England Air Quality

In recent years, it has become increasingly evident that the most persistent air pollutants (e.g., ground-level ozone and fine particles) are inherently a regional problem requiring a regional approach. The problem is particularly difficult in the case of ozone and fine particles since both of these pollutants are formed by a complex series of chemical reactions that occur in the atmosphere and involve pollutants emitted from a variety of sources, often far away and hence involving transport from long distances.

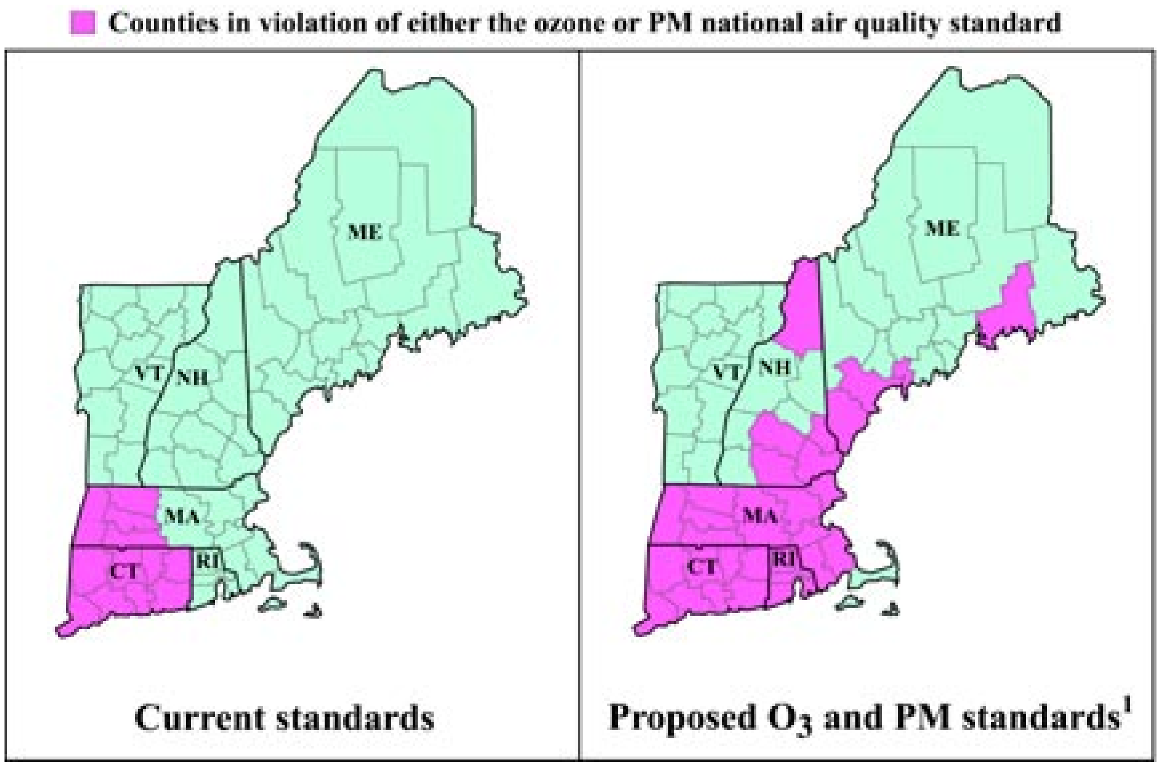

Figure 1. Areas in New England that exceed current and proposed national air quality standards for ozone and/or fine particles (PM).

Nowhere is the regional nature of this problem more evident than in New England. There are currently several counties in southern New England where ozone and/or particulate matter (PM) levels exceed the standard established by EPA to protect public health and welfare (Figure 1). The number of counties in the region that are expected to violate EPA's proposed new standards is considerably greater[1].

The meteorological conditions responsible for pollution episodes vary across the country. In the Southeast, the highest pollution levels are usually accompanied by stagnant air

[1] A.S.L. & Associates, Helena, Montana USA.

masses that allow pollution to build up in the region. However, pollution episodes in New England often occur during periods of reasonably strong winds (Figure 2)[2].

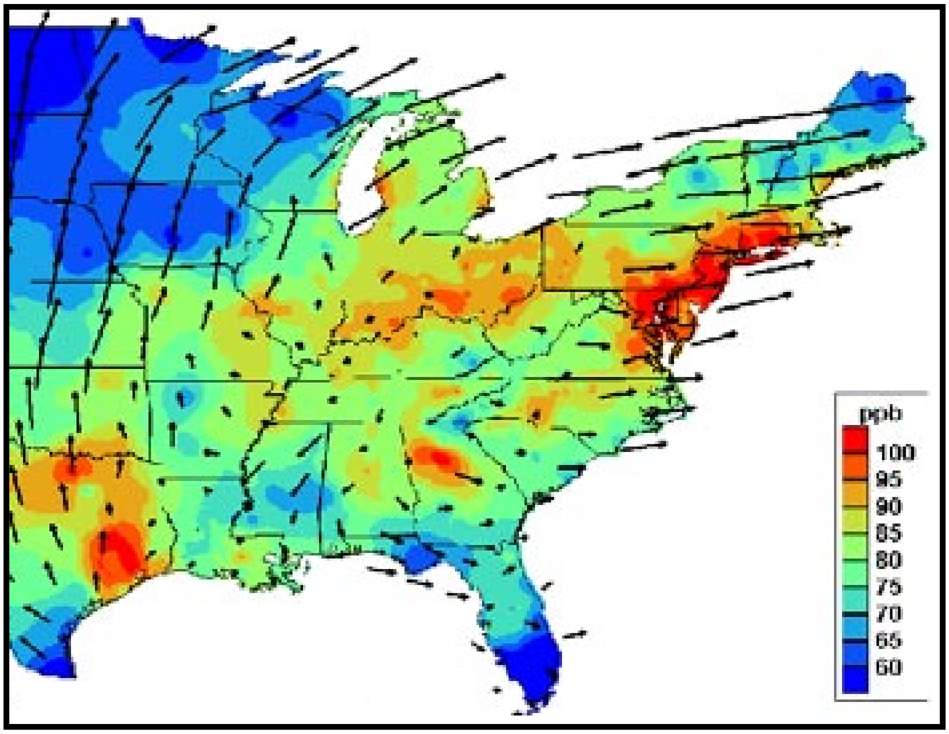

Figure 2. Typical transport winds and ozone concentrations during ozone episodes. The arrows indicate the average wind speed (the longer the arrow the greater the wind speed) and direction during the days with the highest ozone concentrations (see color code).

The sulfur dioxide, nitrogen oxide, and volatile organic emissions responsible for these high pollution levels come not only from the cities and industries in the region, but are also transported on these strong winds from the industrial Midwest and the urbanized eastern seaboard. The situation is further complicated by the natural organic emissions from the abundant forests in New England that also contribute to the formation of ozone and fine particles.

Significant progress has been made in understanding the sources of pollution and the atmospheric processes that control their fate. However, significant knowledge gaps in key areas still remain. The AIRMAP (Atmospheric Investigation, Regional Modeling, Analysis, and Prediction) collaborators have made significant contributions to the current body of knowledge. It is upon this foundation that the proposed program will be built.

[2] Ozone Transport Assessment Group Executive Report, 1997.

AIRMAP

AIRMAP is a NOAA Cooperative Institute, a joint collaboration involving researchers in New Hampshire (University of New Hampshire, Plymouth State College, Mount Washington Observatory and the New Hampshire Department of Environmental Services) and NOAA's Aeronomy Laboratory (AL) and Forecast Systems Laboratory (FSL). AIRMAP is focused on atmospheric chemical and physical observations in rural and semi-remote areas of New Hampshire with the goal of understanding the inter-relationships in regional air quality, meteorology, and climate phenomena.

A network of rural air quality monitoring stations has been established under AIRMAP (Figure 3). These stations provide continuous measures of ozone and fine particles and their precursor compounds as well as meteorological parameters in rural New Hampshire. Through the analysis of these data, a clearer picture of the factors controlling air quality in New England is emerging.

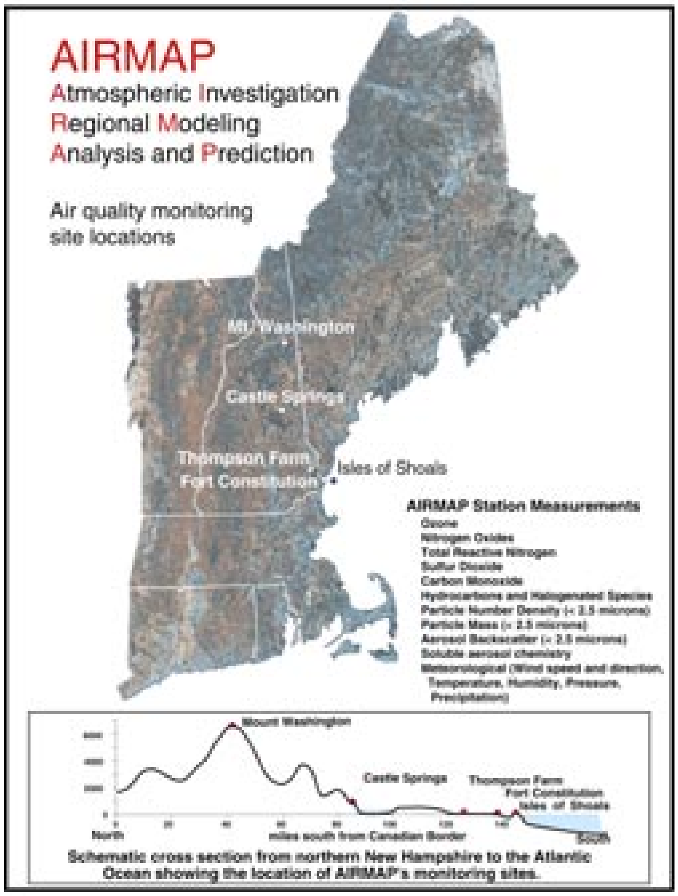

Figure 3. Map showing location of the AIRMAP air quality research monitoring network.

Health of the Atmosphere

NOAA's Health of the Atmosphere (HoA) research program is "focused on the atmospheric science that underlies regional and continental air quality with the goal of improving our ability to predict and monitor future changes, leading to improved scientific input to decision-making." NOAA's participation in the New England Air Quality Study is being supported, in part, by the HoA program. The New England region provides a very useful contrast with past studies conducted under the HoA program in the Southeast, Texas, and the Mountain West. This contrast is a key part of the HoA long-term strategy to examine the role of regional differences (in emissions and meteorology) in shaping air quality.

Summertime Ozone Episodes

The northeastern U.S. had hot and dry summers during 1999 and 2001. Both of these summer seasons were characterized by numerous time periods of hazy stagnant meteorological conditions that lead to O_3 episodes. Preliminary data is shown in Figure 4 for a typical summer 2001 event that occurred during the week of July 20. Regional CO mixing ratios were modest during this time period, fluctuating around 200 ppbv. Hysplit trajectories indicate that the large-scale flow in the boundary layer was consistently from the west to southwest directions. Such a flow regime typically brings quite polluted air parcels into the New England region.

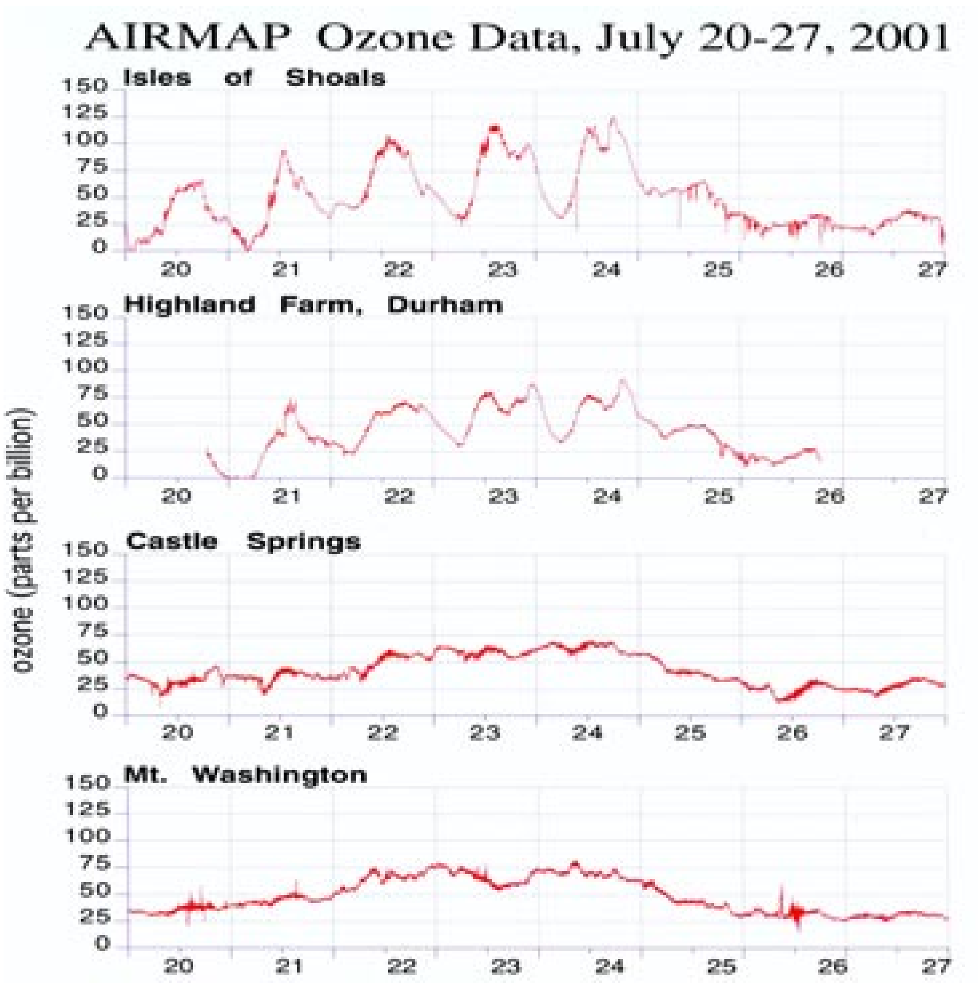

Figure 4. Ozone measured at AIRMAP sites during July 2001 episode.

The peak O_3 mixing ratio at Castle Springs and Mount Washington were in the vicinity of 75 ppbv with little diurnal variation at these higher elevation sites. The O_3 time series for Thompson Farm (data identified as Highland Farm in Figure 4.) and the Isles of Shoals showed significant diurnal variation and a secondary O_3 peak that occurred 4-5 hours after the initial peak in the early afternoon. At both sites the secondary peak was 5 –15 ppbv higher than the first one. One of the goals of the 2002 measurement campaign will obviously be to determine the nature of these multiple peaks, which commonly occur in the New England region. This will involve accessing daily O_3 production, entrainment from aloft, long-range transport, and recycling due to processes such as the sea breeze and nocturnal jets. The magnitude of the daily fluctuations of O_3 at the Isles of Shoals is impressive (~100 ppbv), and points to important local dynamics and associated synoptic forcing that needs to be investigated to understand these data. The coincident timing of the fluctuations at Thompson Farm and the Isles of Shoals suggests that it is a much more complicated than a simple sea breeze scenario. The data that collected during the summer of 2001 will be critical for planning the spatial distribution of AIRMAP and NOAA's measurement resources during 2002.

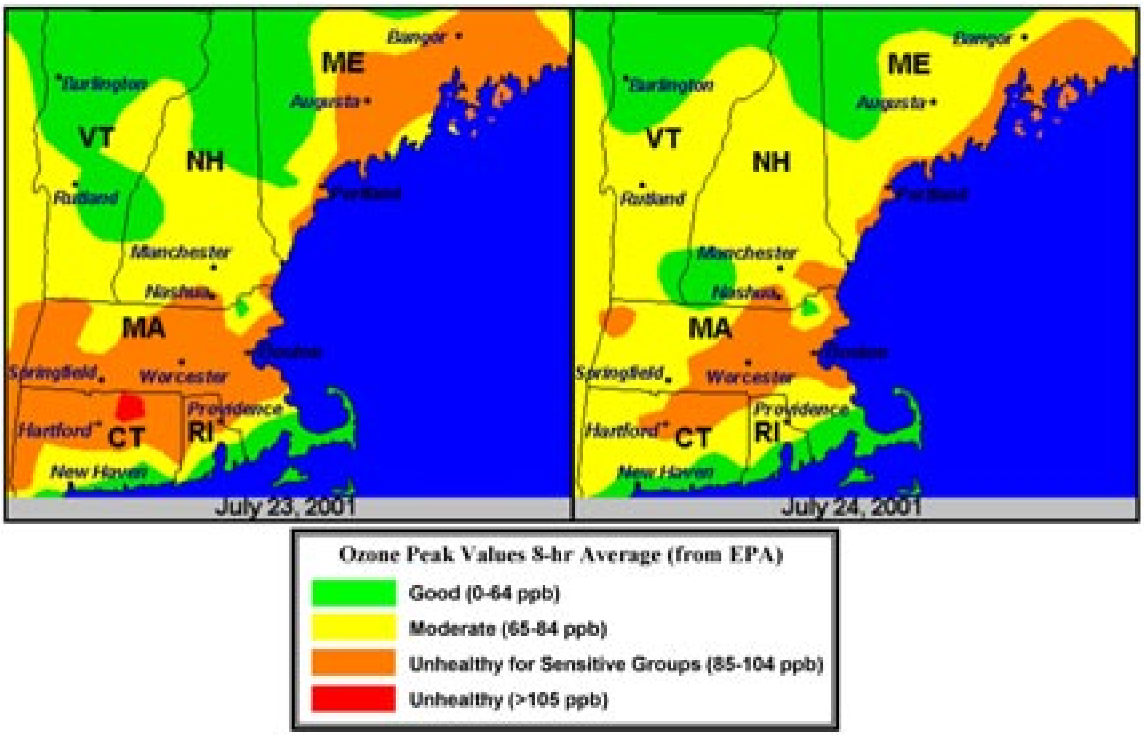

Figure 5. Distribution of ozone throughout New England during two days of the episode.

Regional Emissions

Although New England's emissions of air pollutants are reasonably modest in comparison to other regions of the U.S. there are significant natural and anthropogenic sources that have to be considered in a study of air quality in the region. Emissions of several major pollutants are given for each state in Table 1.

Table 1. Annual state-level anthropogenic emissions and rank for New England states (1998).[3] Emissions are in thousands of short tons.

	NO_x		VOC		SO_2		$PM_{2.5}$	
State	**Emissions**	**Rank**	**Emissions**	**Rank**	**Emissions**	**Rank**	**Emissions**	**Rank**
Connecticut	153	41	156	35	66	41	30	45
Maine	94	45	109	40	53	44	102	36
Massachusetts	304	31	264	29	264	24	72	40
New Hampshire	82	46	74	45	148	34	17	47
Rhode Island	35	50	49	49	12	49	8	50
Vermont	46	49	44	50	16	48	18	46

The distribution of the NO_X and VOC emissions between area and point sources and throughout the region is shown in Figures 5 and 6.

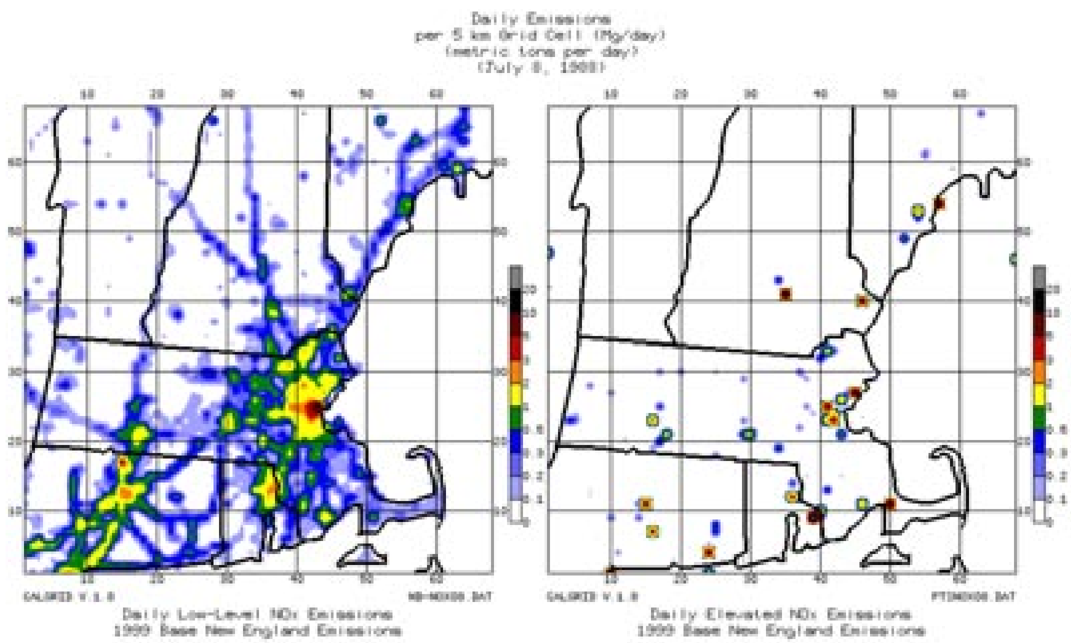

Figure 6. Distribution of NO_x emissions in New England.[4]

The contribution of the major metropolitan areas in Connecticut and Massachusetts as well as some isolated point sources (primarily power plants) is evident.

[3] EPA National Air Pollutant Emissions Trends, 1900-1998, EPA-454/R-00-002, March 2000

[4] Taken from the New Hampshire Department of Environmental Services (NHDES) web site (http://www.des.state.nh.us/ard_intro.htm)

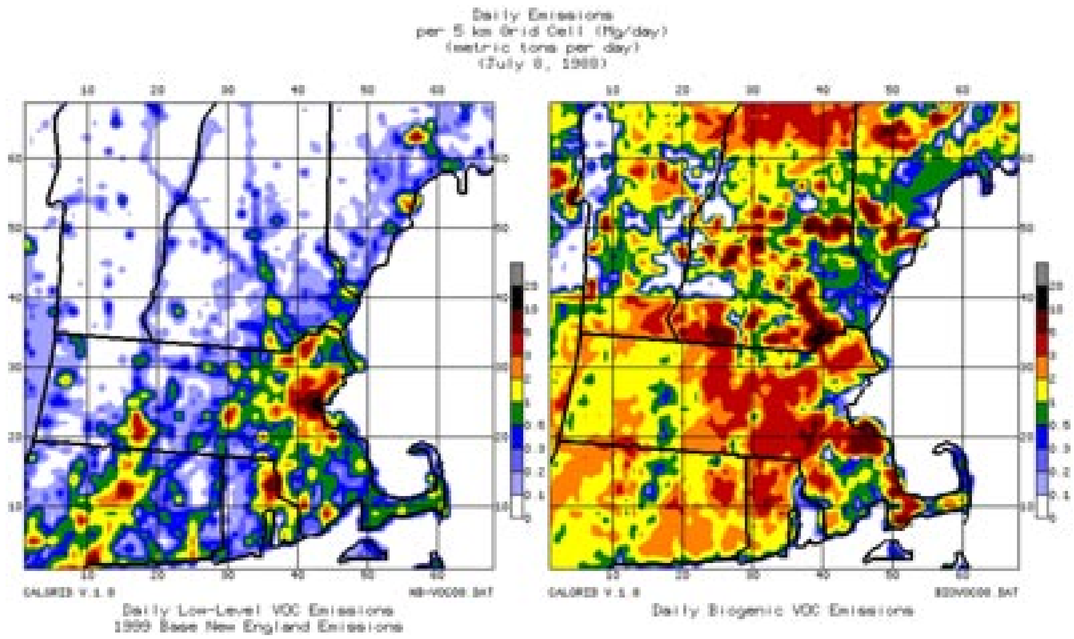

Figure 7. Distribution of VOC emissions in New England[4].

It is clear from the data presented in Figure 7 that natural sources of VOC dominate the emissions and may play an important role in shaping air quality on New England. In fact the most recent inventories suggest that natural sources of VOCs (primarily forests) account for more than 75 percent of the summertime emissions. The relative significance of these emissions is further enhanced when their greater reactivity, compared to anthropogenic emissions, is considered.

Study Themes and Objectives

Clearly, resolving the issues described above is a daunting task requiring a detailed understanding of the processes that control the formation and distribution of air pollution in New England. In order to optimize the management of air quality in New England, the following science questions need to be addressed:

- How well do current air models represent pollution sources and atmospheric processes that shape air quality in New England? How can these models be improved?
- How well can these models forecast air quality (3-5 days in advance)?
- What measurement networks are required to develop and evaluate regional air quality management strategies?
- What is the relative importance of local and transported pollution to air quality in New England?
- What is the relative importance of natural and man-made emissions to air quality in New England?
- What are the linkages between the atmospheric processes responsible for ozone and fine particle pollution? What are the implications for a coordinated mitigation strategy?
- What are the linkages between regional air quality and weather/climate variability?

These needs will be addressed in the research program, which is described below, that builds on an existing collaboration between the scientists in the region, scientists from NOAA's Office of Oceanic and Atmospheric Research (OAR) laboratories, and other interested participants from throughout the U.S. and Canada.

While the regular monitoring of key pollutants and their precursors being conducted under AIRMAP, the state agencies in the region and others provide a valuable data set with which to characterize the air quality and chemical climatology of the region, experience has shown that the information from these networks is most useful when augmented with intensive study periods during which a more comprehensive set of measurements can be made over a wider region. These enhanced measurements can provide detailed information on the controlling atmospheric processes and the inputs needed to properly exercise and constrain air quality models. Therefore, the AIRMAP consortium is proposing to expand its research program to include a series of intensive field experiments focused on New England that will bring together the extensive capabilities of the AIRMAP and other research teams. The proposed new research will be organized under a series of themes, which are described below:

1. ***The role of long-range transport in shaping the regional and extra-regional air quality of New England***

Although New England does have air pollution sources of its own, they are relatively modest in comparison to those in much of the rest of the United States. However, polluted air masses from the Northeast Corridor, the Midwest, and Southern Canada can significantly impact air quality in New England. A more predictive understanding of the role of long-range transport will serve to guide more effective management strategies while enhancing the overall understanding of the processes that control the formation and distribution of air pollution. Specific scientific questions to be addressed include:

- What is the role of nighttime chemistry and transport in determining the distribution and composition of the regional pollution mix?
- How do the chemical processes in the atmosphere vary with the seasons? What are the main chemical processes that determine atmospheric transformations during the winter months?
- What is the role of the region's complex terrain in promoting the exchange of pollution between the polluted boundary layer and the free troposphere?
- How does the mixing of aged pollution with fresh emissions during transport affect pollution formation and distribution?
- Which source regions have the greatest impact on air quality in New England? What is the magnitude of the impact relative to local sources?

2. ***The role of biogenic emissions in local and regional air quality in New England***

Ozone is formed in the atmosphere through a complex series of reactions involving volatile organic compounds (VOCs) and nitrogen oxides (NO_x) in the presence of sunlight. The abundant forests of New England are a significant source of reactive (VOCs) that contribute to the production of ozone and the formation and growth of fine particles. Intensive field campaigns conducted by NOAA in the Midwest and Southeast have demonstrated the important role that biogenic VOCs can play in pollution formation. However, this work has focused on isoprene, which is emitted from southern deciduous forests. The ozone- and particle-producing properties of pinenes and other terpenoid compounds emitted by the coniferous forests of the North are very different than those of isoprene (e.g., temperature). The impact of these natural emissions on regional air quality is not well understood. Specific scientific questions to be addressed include:

- What is the relative role of biogenic and anthropogenic VOCs in the formation of ozone in the region?
- What is the relative role of biogenic and anthropogenic VOCs in the formation and growth of fine particles in the region?
- How does the atmospheric chemistry of biogenic VOCs vary from day to night?
- How does this affect the seasonality of pollution formation?

3. *The role of the sea-breeze/land-breeze circuit in influencing air quality in New England*

The sea-breeze/land-breeze circuit (SBLB) is a meso-scale circulation of air caused by the differential heating and cooling of the land- and sea-surfaces in the coastal zone. It is driven by the diurnal cycle of solar insolation and the differing heat capacities of land surfaces and seawater. The SBLB phenomenon has the potential to profoundly effect New England's air quality. Re-circulation of polluted air between the coastal marine and eastern New England coastal areas is evidenced by the ozone episodes shown in Figures 4 and 5. The chemical processing of continental air in the local marine environment could, for example, substantially alter its reactive nitrogen content. This processing could subsequently influence the photochemical state and ozone production potential of the polluted air parcels. These processes are known to involve complex heterogeneous chemistry, which need to be studied in detail. Specific scientific questions to be addressed include:

- What geographic area in eastern New England is most influenced by the SBLB circulation?
- What role does the nocturnal jet play in the SBLB circulation?
- What important chemical processing of polluted continental air occurs in the coastal zone?
- How does the chemical processing differ from daytime to nighttime?
- What are the time scales of these chemical processes?

4. *Evaluation of air quality forecast systems*

Air quality forecasts are currently being performed for all of the major metropolitan areas of the U.S. EPA collects and displays ozone forecasts for U.S cities on its AIRNOW web site (http://www.epa.gov/airnow/). The methods used to produce these forecasts vary from relative simple climatological approaches to the application of sophisticated photochemical grid models[5]. The need for reliable air quality forecasts is clear and growing. However it is important to continuously evaluate the skill of the techniques to select the most suitable approach for each application and to improve the skill of the techniques being employed. Two kinds of evaluations are needed:

- <u>Operational evaluation</u> – a direct comparison between the forecast pollution fields (e.g., ozone concentrations) and the observed pollution distribution (e.g., ozone measured in the regulatory network). An operational evaluation is designed to answer the question – How close was my prediction to what actually occurred?

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[5] CENR Air Quality Research Subcommittee, Air Quality Forecasting – A Review of Federal Programs and Research Needs (http://www.al.noaa.gov/AQRS/reports/Forecasting.html)

- Diagnostic evaluation – an evaluation on the performance of the processes of prediction. In other words, a diagnostic evaluation will tell you if you got the right answer for the right reason. As the name implies, a diagnostic evaluation requires the measurement of parameters (both meteorological and chemical) that control pollution formation and distribution.

Ozone forecasts for the New England region are currently being performed by a number of groups including: MCNC, NOAA's Forecast System's Laboratory, NESCAM, and the air quality groups in each of the states. An evaluation of forecast performance for these systems is ongoing.

5. *Linkages between air quality and climate*

The meteorological conditions that promote adverse air quality in New England are tightly coupled to the climate systems. The relative frequency of air mass stagnation, the development of shallow inversion, which lead to "home-grown" pollution events and transport patterns that bring pollution from the industrial Midwest and urban areas along the East Coast determine the quality of the air to which the citizens of the region are exposed. Also, the polluted air that leaves New England can ultimately influence air quality in Eastern Canada and ultimately the North Atlantic and Europe. A better understanding of the linkages between climate and air quality is needed if we are to be able to reliably predict the influence of predicted changes in climate on future air quality.

Approach

The primary goal of the New England Air Quality Study is ***an improved understanding of the atmospheric process that control the production and distribution of air pollutants in the New England region.*** The Science plan to accomplish this goal has three components:

<u>Long term monitoring</u> – The University of New Hampshire has taken the lead in establishing a new comprehensive air quality monitoring network in New England. The measurements made at these sites will augment the data already being collected in the existing regulatory monitoring network and at nearby research sites (e.g., Whiteface Mountain and Harvard Forest). The data collected at this ensemble of sites will provide insights into the chemical climatology of the region, long-term trends in air quality, and information on meteorological and chemical processes.

<u>Intensive field studies</u> – The basic set of measurements plan for the AIRMAP network, although extensive, provides only a partial view of the chemical and physical processes that control pollution formation and transport. Insight into these processes requires that that view be expanded to include a wider array of chemical and physical measurements and an examination of key parameters over the full three-dimensional extent of the atmosphere. The intent is to conduct two major field intensives (during the summers of 2002 and 2004) that will make more extensive use of additional measurement capability, remote sensing technology, and instrumented aircraft than is feasible in a long-term monitoring effort. The data collected during these intensives will provide a more complete picture of the atmosphere in the New England Region, its dynamics and constituents than has been previously possible. The use of instrumented aircraft will also allow the tracking of polluted air masses as they enter and leave the New England region.

<u>Modeling analyses</u> – Air quality models are the main conduit for the transfer of scientific understanding of the atmospheric processes that control air quality to the management of air quality. The decisions and strategies developed by the regulatory and policy communities are only as good as these models are in describing the key atmospheric processes. Thus in the New England Air Quality Study we plan to use air quality models in three distinct ways:

- As tools to be evaluated – The data collected in the long-term modeling effort and the intensive field studies will be used to evaluate model performance and skill. The comprehensive data sets obtained during the intensives can be used to constrain the models in such a way that performance of individual modules (emissions, meteorology, chemistry, etc.) can be properly evaluated. Initial evaluation efforts will focus on the photochemical grid model being used to produce ozone forecasts.

- As forecast tools – The air quality forecasts currently being produced will be used on a campaign basis to plan the deployment of mobile sampling platforms (ships and aircraft). The availability of reliable forecasts will greatly improve the probability that mission goals will be accomplished and increase the productivity of these expensive assets.

- To aid in data analysis – The use of air quality models will be an integral part of the analysis of data from both the long-term monitoring network and the intensive field campaigns. Models provide a very effective mechanism for integrating data sets from ground-based and airborne platforms.

Staging of Field Intensives

The two field intensives have been scheduled to take advantage of an evolving understanding of the factors that shape air quality in New England. The intent of the 2002 intensive is to map out the surface concentrations of ozone and fine particles and their precursors. The knowledge gained in this effort will be used to refine the goals and measurement strategies for the 2004 intensive when the aircraft will be used to extend the horizontal and vertical extent of the measurements. Thus, the 2002 scoping study will help to maximize the use of the aircraft facilities planned for 2004.

Measurement Systems

Regulatory Network

The network of regulatory monitors that is operated by states in New England provides a valuable source of information on the distribution and trends in air quality. The states in the region operate approximately 55 ozone monitoring stations during the ozone season (i.e., April 1 through September 30)[6]. The network of stations is shown in Figure 7. For the four-year period from 1997 through 2000 EPA reports an average of 28 days per year (summer months) when New England's air exceeded the 8-hour ozone standard. The data from some of these stations are available through the EPA AIRNOW system. Several sites in New Hampshire are being polled daily and included in the AIRMAP database.

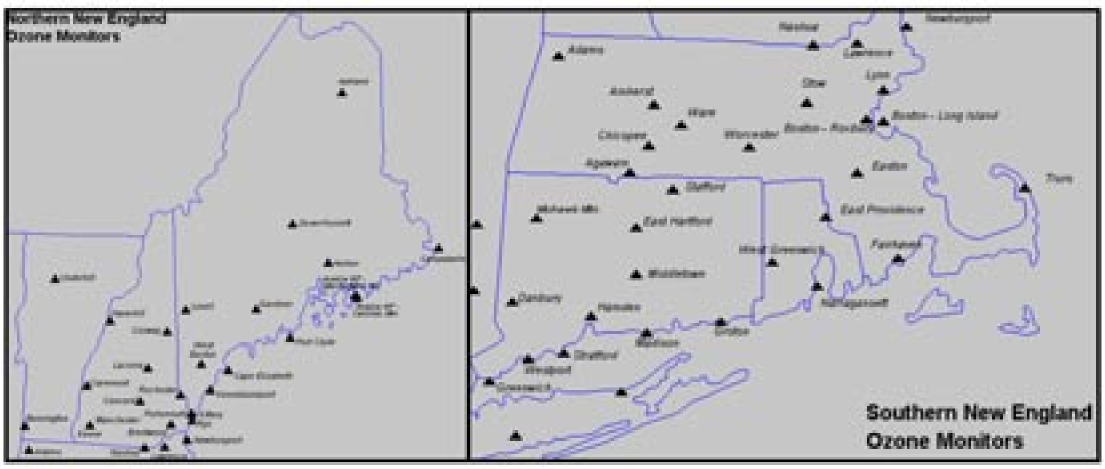


Figure 7. Location of regulatory ozone monitors operated by the states in New England.

The AIRMAP Network

AIRMAP has established three long-term measurement sites for documenting and studying persistent air pollutants such as ozone and fine respirable aerosols on various time scales in the New England atmosphere. These sites represent strategically chosen locations to provide a gradient in elevation from sea level (Highland Farm in Durham) to 400 m at Castle in the Clouds (Moultonboro) and up to 2000 m at the summit of Mount Washington (North Conway). Each of these sites is being equipped with research-grade instrumentation for measuring critical air pollutants in the non-urban atmospheric environment of New England (Figure 3).

[6] EPA Region 1, http://www.epa.gov/region01/eco/dailyozone/omssites.html

The air quality monitoring instrumentation is being custom fabricated and tested in the AIRMAP/Climate Change Research Center laboratories at UNH. At each site all of the instruments are controlled by a central computer to provide continuous data of the highest quality with an average one-minute time resolution. A National Instruments data acquisition interface is being used to control the instruments and store the raw signals. Internet access at the sites allows instrument monitoring, data archiving, and real-time display of atmospheric data.

AIRMAP instrumentation is being implemented with the highest regard for quality measurements in the non-urban environment. The instrumentation at each site is operated in consultation with scientists and staff at the NOAA Aeronomy Laboratory. The extensive database being generated by AIRMAP is rigorous and defendable.

Table 2. The AIRMAP Core Measurement Package.

PARAMETERS	METHOD
<u>All Sites</u>	
O_3	TEII Model 49C
CO	TEII Model 48C – modified
CO_2	Licor IR
NO	TEII Model 42C-TL – modified
NO_y	TEII Model 42C-TL – modified (Mo converter)
SO_2	TEII Model 43C – modified
$J\mathrm{NO}_2$	Metcon, Inc.
CN	TSI 3022A
Aerosol Scattering (450, 550, 700 nm)	TSI Model 3563
Aerosol Absorption (550 nm)	Radiance Research PSAP
Aerosol Soluble Ions	Teflon Filter/Dionex IC
Hydrocarbons/Halocarbons	Entech /Shimadzu
Wind Speed/ Direction	Qualimetrics Model 2020
Temperature/ Humidity	Qualimetrics Model 5190
Barometric Pressure	Qualimetrics Model 7120
<u>Additional at Thompson Farm</u>	
PM2.5 aerosol mass	URG Custom Built
PM2.5 aerosol composition	URG Custom Built
Direct-normal, total-horizontal, Diffuse-horizontal irradiances	Yankee Environmental MFR-7

Atmospheric Physical Measurements

The physical or meteorological situation in New England is quite complex. Some of the important physical questions are:

- How often and where is air near the surface well-mixed with respect to air above the surface (at a few hundred meters, for example)?
- What is the role of coastal phenomena such as the sea breeze in transport of pollutants toward or away from population centers and monitoring sites?
- What is the role of complex terrain such as that of northern New Hampshire in vertical mixing?
- How is the diurnal cycle of atmospheric stability in New England similar to or different from that in other areas?

Long-range pollutant transport preferentially occurs well above the surface, where wind speeds are higher and fewer obstacles are present. In order for pollutants transported at upper levels to affect the surface environment, vertical mixing must take place. This can be caused by daytime surface heating, by transport of cooler air over a warmer surface, or by mechanical mixing over rough terrain. Conversely, warm polluted air transported over a cooler surface (such as cool ocean water) becomes stable and isolated from the surface. A likely scenario is that warm polluted air from the East Coast metroplex is isolated above the surface during transport over the cool ocean and Gulf of Maine. When such air masses reach warm land again in New England during the day, they can be mixed vertically to the surface.

Instruments capable of measuring vertical profiles of physical quantities are key to understanding these phenomena. One boundary layer wind profiling radar (profiler) has been deployed at Portsmouth, NH to provide preliminary data for planning purposes and will remain in place throughout the study. A second profiler will be deployed on the Isles of Shoals during the 2002 intensive. A Doppler LIDAR to be deployed at a coastal location (Rye Harbor State Park) during intensive periods will provide high-resolution data on coastal flows. Figure 8 shows an example of the passage of a bay breeze front observed by a Doppler lidar during the 2000 Texas Air Quality Study. The convergence at the head of the front typically produces substantial vertical mixing. The bay breeze, indicated by the positive velocities at the surface beyond 4

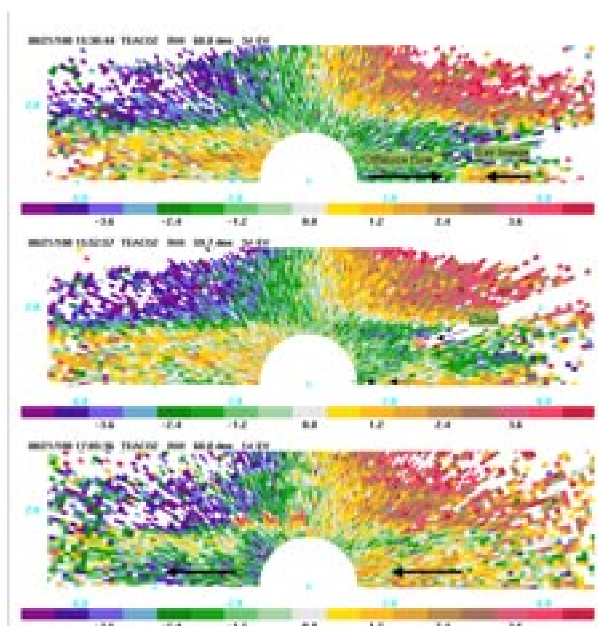


Figure 8: NOAA/ETL Doppler lidar range-height scans depicting the reversal of wind flow due to the intrusion of the bay breeze, measured at the LaPorte site. The blue numbers indicate distance, in km, from the lidar, which is located at x=z=0. The color scale at the bottom of each plot indicates the radial wind

km horizontal range, is quite distinct as it propagates in opposition to the offshore flow. In the middle plot, the bay breeze front was ~2 km from the lidar, and as is common with such a front, a small cloud formed near the converging winds. The bottom plot shows weak onshore flow at least 1 km deep.

A micro-scale surface-observing network in coastal southern New Hampshire and northern Massachusetts will provide detailed information about the sea breeze and other coastal effects on scales of a few kilometers. The summer 2002 field campaign will offer an opportunity to gather preliminary data on the SBLB processes. Initially, a simple diagnostic model is being used for comparison of wind data collected in a fine-scale observational network along the Atlantic coastline. The network and diagnostic model has a scale resolution of several kilometers (Figure 9). The details of the coastal dynamics studied during summers 2001/02 will be used to facilitate larger-scale investigations using MM5. These model investigations will be done in collaboration with scientists at the NOAA Forecast Systems Laboratory and also involve their coupled MM5/chemistry model.

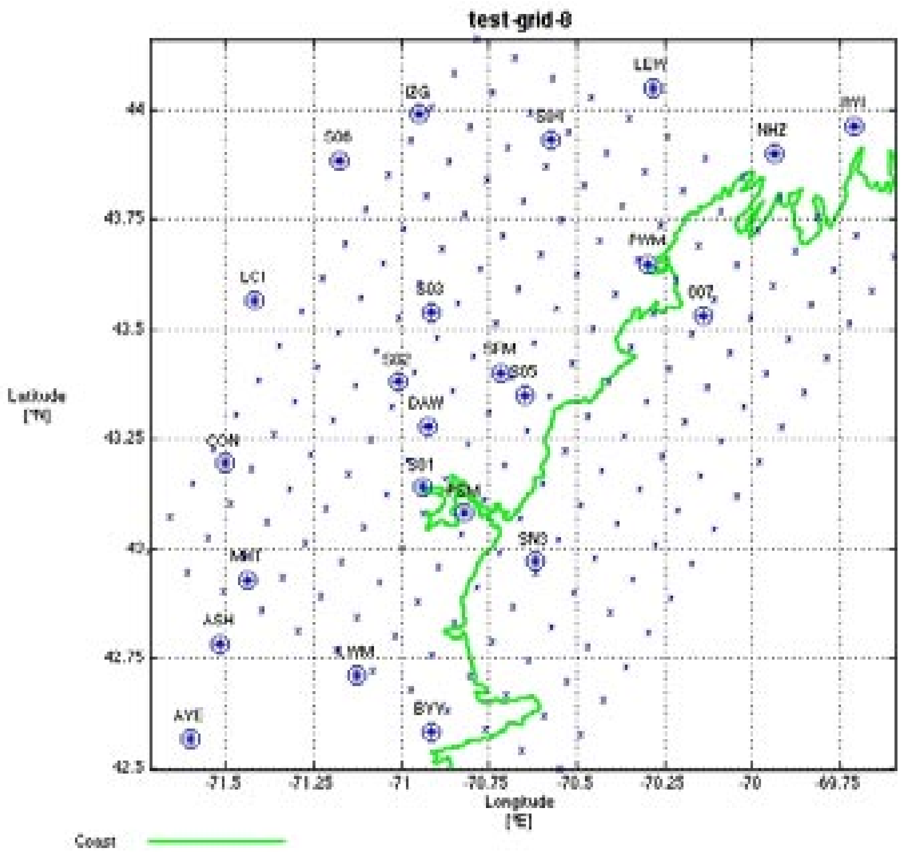


Figure 9. Micro-scale weather observing network along the eastern coastline of New England. Most surface observing stations are indicated with the corresponding International Civil Aviation Organization (ICAO) identifier. Stations SNN are "special locations" set up by UNH for AIRMAP, or coordinated for this purpose with a cooperating state or local agency.

Mobile Monitoring Systems

During the 2002 and 2004 intensive periods the long-term AIRMAP measurements will be augmented with data from a variety of mobile platforms. These platforms will be used to extend the spatial coverage of the measurements both within and outside the region. Current plans call for the use of NOAA Ship Ronald Brown to study air quality in the coastal region of New England during the summer of 2002 and to deploy two instrumented aircraft during the summer of 2004. These platforms and the proposed applications are described below.

NOAA Ship Ronald H. Brown

Some of the highest ozone concentrations in New England have been recorded at monitoring sites on or near the coast. These episodes can result from the re-circulation of polluted air from within the region or long-range transport from outside the region (e.g., Figure 10). A more complete understanding of the relative importance of local versus distant sources on air quality in New England is an important first step in the development of an effective plan to improve air quality for the citizens of the region.

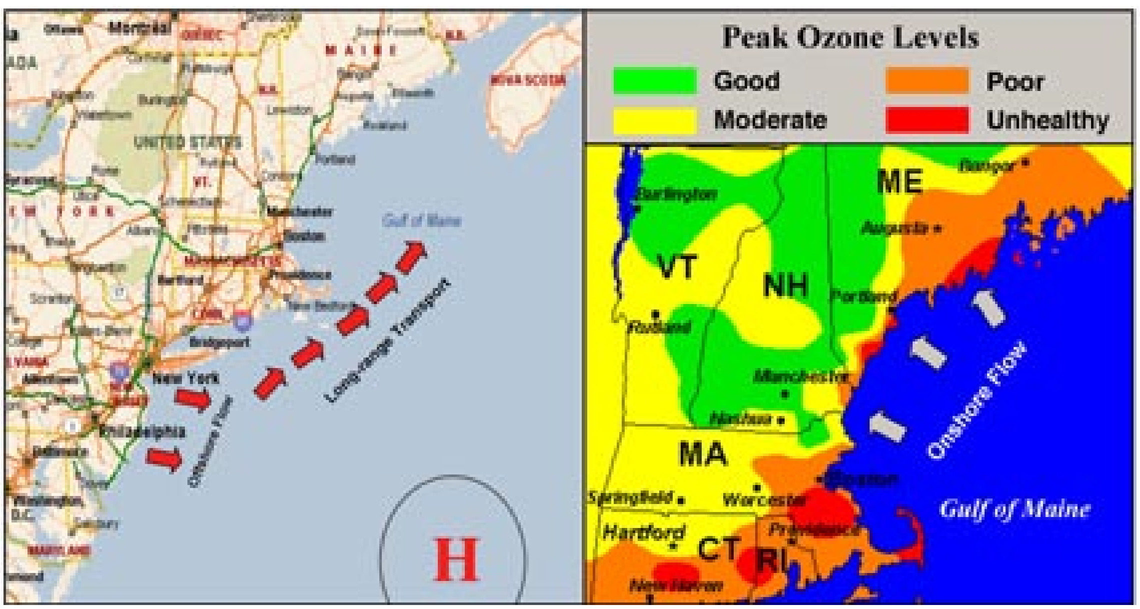


Figure 10. The circulation set up by the Bermuda High during the summer months can bring polluted air from densely-populated areas of the Eastern Seaboard into the Gulf of Maine. Local synoptic flow within the Gulf (land – sea breeze) can then bring the polluted air into coastal New England[7].

[7] Ray, J.D. et al., Surface level measurements of ozone and precursors at coastal and offshore locations in the Gulf of Maine, J. Geophys. Res., 101, 29005-29011, 1996.

The study planned for the summer of 2002 will focus on the coastal area of New England and will take advantage of the heavily instrumented area along the New Hampshire seacoast to better understand the interplay between the land – sea breeze, and the synoptic flow in the coastal boundary layer to determine the cause of the high pollution episodes along the coast. The University of New Hampshire has established a comprehensive atmospheric monitoring site at Durham New Hampshire (Thompson Farm) and has added additional measurements to a site on Appledore Island, one of the Isles of Shoals, approximately eight miles offshore. UNH has also established a high-density meteorological network along the coast. NOAA has augmented these measurements with a radar wind profiler at Pease N.H. and a Doppler lidar at Rye Harbor State Park, an air monitoring site operated by the state of New Hampshire.

Proposed Deployment of the Ronald H. Brown

Clearly the transport of polluted air within the Gulf of Maine plays an important role in shaping the air quality in coastal New England. The source of the polluted air is less clear. Re-circulation of pollution from urban areas within New England and long-range transport (e.g., from the Washington – New York corridor) both have to be considered. The conditions in the Gulf are also expected to play a role as the marine boundary layer is expected to act as a huge chemical reactor converting primary pollutants like nitrogen oxides and organics into more-toxic secondary pollutants like ozone and fine particles.

Figure 11. The NOAA Research Vessel Ronald H. Brown.

An instrumented ship is an ideal way to study the meteorological and chemical processes that are occurring of the coast of New England. A ship can be used to sample polluted air masses as they move offshore, study the chemical transformations in the polluted marine boundary layer, and characterize polluted air masses at they move onshore. Previous attempts to perform these measurements from sites on shore have resulted in data that is difficult to interpret due to contamination by local land-based sources.

The operational capabilities, and facilities on the Ron Brown (Figure 11) make it the ideal platform for these kind of studies. The availability of an on-board radar wind profiler is particularly important.

Instrumentation

The Aeronomy Laboratory and the Environmental Technology Laboratory have in recent years conducted several highly successful air quality studies. The experience developed in these joint studies has resulted in a comprehensive suite of instrumentation that allows the characterization of atmospheric dynamics and chemistry in complex environments. Of particular importance for this study are the techniques that have been developed to distinguish among various source types and regions.

Table 3. Proposed air quality instruments for deployment on the Ron Brown.

Parameter	Method	Performing Laboratory
Ozone	UV Absorbance	AL
Ozone	NO Chemiluminescence	AL
Carbon Monoxide	Nondispersive IR	AL
Carbon Dioxide	Nondispersive IR	AL
Sulfur Dioxide	Pulsed Fluorescence	AL
Nitric Oxide	Chemiluminescence	AL
Nitrogen Dioxide	Photolysis Cell	AL
Total Nitrogen Oxides	Au Tube Reduction	AL
PANs	GC/ECD	AL
Alkyl Nitrates	GC/FID	AL
Photolysis Rates	Spectral Radiometer	AL
Ionic Aerosol Composition	PILS	PMEL/GIT
Size-resolved aerosol composition and gravimetric mass	Impactor (IC, XRF, and thermal-optical OC/EC).	PMEL
Aerosol Size and Composition	Aerosol Mass Spectrometer	AL/Aerodyne
Aerosol scattering (450, 550, 700 nm)	TSI Model 3563 Nephelometer	PMEL
Aerosol absorption (550 nm)	Radiance Research PSAP	PMEL
Aerosol number	CNC	PMEL
Aerosol size distribution	twin DMAs and an APS	PMEL
Continuous Specation of VOCs	PTR-MS/CIMS	AL
VOC Speciation	GC/MS	AL
Ozone/Aerosol Vertical Profiles	DIAL lidar/Aerosol backscatter	ETL

Operational Planning

NOAA's Forecast System's Laboratory is running an experimental air quality forecast model over the eastern U.S, during the summer months. The model employs fully coupled meteorological (MM5) and chemical modules to predict ozone fields up to 36 hours in advance. The AIRMAP routine and intensive measurements provide one of several data sets that will be used to evaluate and improve this model. The availability of these forecasts also affords the opportunity to optimize the deployment of a sampling platform like the Ron Brown through the selection of sampling strategies tailored to the expected meteorology and air quality. This process would be farther facilitated through the use of one of FSL's FX-Net systems that are being updated to include real time air quality data and model forecasts under the current AIRMAP program.

Sampling Strategy

The instrumentation planned for deployment on the Ronald Brown will allow the characterization of a wide range of gaseous and particulate pollution. This will be accomplished primarily through fast-response *in situ* sampling augmented with the ozone/aerosol profiling capability of the DIAL lidar. The lidar is particularly important when sampling in a stable marine boundary layer as it will provide a vertical context for the ship-board measurements.

As discussed above, the sampling cruises planned for the Ronald Brown are intended to provide insight into the processes that control the high pollution episodes along the coast of New England. The sampling on board the Ronald Brown will be focused on three major scientific objectives:

1. Characterization of Sources – It is important to characterize the mix of emissions that impact the region whether they come from sources within or outside the region. To meet this objective a number of near-shore survey tracks are planned under conditions when the polluted continental air would be expected to transport into the surface marine layer (i.e. nighttime, early morning, or late day)
2. Study of Transport and Transformation Processes – The marine environment is unique both in terms of the dynamics (mixing and transport) and chemistry. Although a great deal is known about the transport and chemistry of polluted air masses and plumes over land very little is known about the processing that occurs in the marine environment. The compliment of instruments on-board the Ron Brown will be used to document the evolution of polluted air masses in the Gulf of Maine during the entire diurnal cycle.
3. Study of Coastal Impacts – The impact of polluted air masses transported over the Gulf of Maine is evident in the ozone monitoring record for the region. It has been hypothesized that the complex dynamics of the sea-breeze/land-breeze circuit (SBLB) plays a major role in transporting polluted air off the Gulf of Maine into coastal New England. To address this objective the Ron Brown will be deployed near the heavily instrumented region along the New Hampshire coast (e.g. Figure 9) to participate in a coordinated study of the SBLB.

Sample Ship Tracks

A number of generic ship tracks are proposed below that are designed to address the objectives listed above. These should be considered as preliminary and subject to change as the planning for the intensive proceeds and upon review by NOAA's Office of Marine and Aviation Operations. Naturally, the exact orientation and location of the ship tracks will have to be adjusted in accordance with safety considerations and the pollution and weather forecasts. Also a series of measurement comparisons with the monitors on the Isles of Shoals are planned when the Ron Brown is located in the vicinity and are not discussed here.

Sampling During Transit

We would propose to integrate the air quality instrumentation at the Ron Brown's home port, Charleston S. C. This would afford the opportunity to collect data during the transit cruise to and from the Gulf of Maine. NOAA/OAR has conducted several studies in the past to better understand pollutant transport off the east coast of the United States. The *in situ* data and the profiles provided by the ETL DIAL lidar that could be obtained on the transit cruise will provide valuable new data and important new information on the magnitude and composition of pollution leaving the eastern United States. Some options for the transit cruise are shown in Figure 12.

Figure 12. Proposed ship track options for transit cruise to and from the Gulf of Maine.

The timing for this cruise will be dictated to a large extent by the schedule for the study. The ship has been assigned to the study for the period July 10 through August 9, 2001. The choice of transit track would be determined based on the weather forecast for the period of the cruise. For example, the inshore track might be more appropriate for the return to avoid following winds (and the associated contamination from the ship exhaust) resulting from the circulation around the Bermuda high.

This track will primarily address objective number 1, characterization of emissions.

Boston/NY Plume Study

An analysis of data collected on the Isles of Shoals during the summer of 2001 indicates that the highest ozone concentrations (sometimes in excess of 120 ppb) were associated with transport from the southwest. This suggests that transport of the Boston urban plume into the Gulf of Maine may be a significant source of regional ozone during these episodes. The Boston plume may be a composite of fresh, local emissions and more aged emissions since Boston is often downwind of the NY/NJ metropolitan complex, which

Figure 13. Proposed ship tracks Boston/NY urban plume study.

could result in a composite plume containing emissions and byproducts from several urban areas[8]. Three ship tracks are proposed to sample these plumes (Figure 13). One survey track is proposed to map out the various plumes that enter the Gulf of Maine under southwesterly transport. A second track is confined to Massachusetts Bay to characterize the Boston plume in the early stages of transport. This track could be repeated throughout the day to document the vertical distribution of the offshore pollution as the land warms. The third track is designed to capture the mixed plume from the NY/NJ area as it enters the Gulf of Maine. Tracks one and two would begin early in the morning. If the NY/NJ plume is located during the survey track the cruise could continue following track three.

The tracks are oriented cross-wind to account for the expected heterogeneity of these plumes. The Brown would work its way downwind following the chemical evolution of the plume as it is transported away from the immediate area of Boston. If possible these plumes would be tracked into the night either on a single cruise or on separate cruises.

These tracks will address objectives one (characterization of sources) and two (study of transport and transformation processes).

Sea-breeze/ Land-breeze Circulation

The study of the SBLB circulation is a major objective the New England Air Quality Study. The ship tracks shown in Figure 14. are designed to augment the intensive measurements planned for the New Hampshire coast to address this issue.

Figure 14. Proposed ship tracks designed to study the sea-breeze/land-breeze circulation.

[8] Sillman, S. et al., Ozone production in urban plumes transported over water: Photochemical model and case studies in the northeastern and Midwestern United States, J. Geophys. Res., 98, 12687-12699, 1993.

The proposed tracks run along and perpendicular to the sea-breeze front. This experiment would be conducted under reasonably weak synoptic forcing when the Sea/Land breeze would be expected to have a significant impact on local transport. The parallel and perpendicular tracks shown in Figure 14 would be alternated as feasible during the day beginning at dawn to capture as much of the diurnal cycle as possible. The cruise up into Portsmouth Harbor and the Piscataqua River would provide a cross-sectional view of the front. Each of these legs also provides an opportunity to compare with measurements on the Isles of Shoals. The parallel track should be performed as close as possible to the coast consistent with safe operation of the vessel.

These tracks would address objective number three (coastal impacts) above.

Onshore Flow – Northern Sector

Many parts of the Maine coast are impacted by pollution that has been transported long distances. Acadia National Park has recorded 1-hr averaged ozone concentrations in excess of 200 ppb even though it is located in a remote part of the coast far from any local pollution sources. A survey cruise is proposed (Figure 15) to examine the transport of polluted to the northern sector of the New England coast. This experiment would be conducted under southerly or southeasterly flow that is bringing polluted air from the Washington/N.Y. corridor into the Gulf of Maine and then ultimately to the Maine coast.

Figure 15. Proposed cruise to examine transport of polluted air onto the coast of Maine.

If possible, the cruise would be timed to take advantage of an alongshore sea-breeze front that is producing onshore flow. Under favorable conditions this cruise would provide additional insights into the dynamics of the sea/land breeze circulation.

NOAA WP-3

During the summer of 2004 NOAA proposes to use an instrumented aircraft to study the transport and transformation of air pollution into and within New England. This aircraft has sufficient range and endurance to survey large areas. Over the past few years the Aeronomy Laboratory has developed and integrated a set of in-situ instruments to study photochemistry and aerosol processes on this platform. The current instrument package is described in Figure 15. This platform would be deployed to address three main objectives:

- To quantify the transport of ozone and fine particles and their precursors into and out of the New England region. Pollution from major upwind source areas will be tracked and the changes in pollution distribution that results from chemical processing, depositional losses, and venting to the free troposphere quantified.

- To determine the rate and efficiency of ozone and fine particle formation within New England. Plume studies downwind of the major urban areas and point sources (e.g., power plants) within the region will provide a perspective of the relative contribution of regional sources to air quality in New England. The influence of natural VOCs will be investigated through the study of plumes in regions with differing biogenic VOC emissions. The NOAA WP-3 instrument package included the capability to characterize the composition and morphology of atmospheric particles with fast time response, which will be particularly helpful in the study of aerosol formation and growth.

- To determine the mechanisms and quantify the rates of chemical transformations that occur during the night. Nighttime processing of air pollution is believed to be very important during multi-day transport. These process may, to a large degree, determine the mix of pollution that reaches distant impact areas, such as New England. NOAA's measurement capabilities have recently been expanded to include two species that play an important role in nighttime chemistry (NO_3 and N_2O_5). This capability, when combined with the other measurements on the NOAA WP-3, will allow the nighttime chemical system to be characterized in detail.

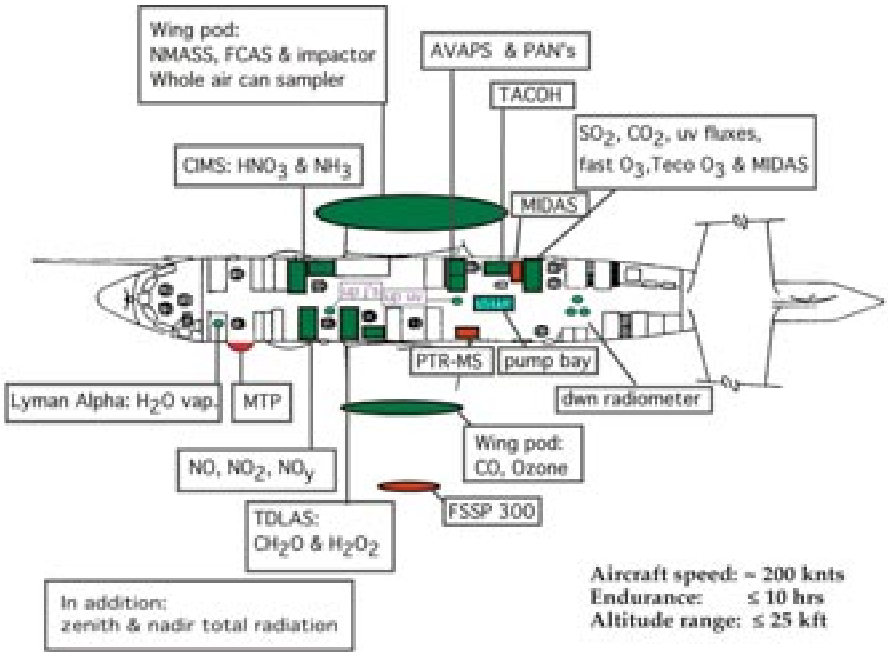
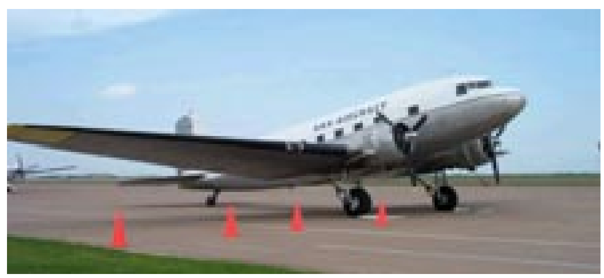


Figure 15. Instrument layout on the NOAA WP-3 research aircraft.

NOAA Airborne Lidar



The NOAA Environmental Technology Laboratory (ETL) airborne ozone Differential Absorption LIDAR (DIAL) has been deployed on a variety of aircraft in past air quality studies (the DC-3 used in the TEXAQS 2000 study is shown on the right). The downward-looking LIDAR system provides vertical profiles of ozone and aerosol backscatter below the flight path. The aircraft usually flies at a constant altitude (~3500 m above the surface). In addition to providing valuable information on the distribution of ozone and aerosols in the atmosphere, the aerosol backscatter can also be used to map the depth of the polluted boundary layer.

During the 2004 intensive field campaign, ETL hopes to add a downward looking Doppler lidar to the remote aircraft to provide simultaneous observations of wind and ozone profiles. Such measurements would yield detailed information on the spatial variability of the transport of ozone and aerosols, as well as provide important intercomparison data for diagnosing and validating model performance.

This platform would be deployed to address three main objectives:

- To characterize the transport and vertical structure of ozone and fine particles under land-sea breeze recirculation. The coastal environment has extremely complex transport and mixing dynamics especially under light wind conditions. During these periods the land-sea breeze circulation can move local pollution offshore and return that pollution, or pollution transported into the marine environment from other regions, when the sea breeze sets up. The ETL airborne LIDAR has been used very successfully previously in Houston TX to study a similar situation where high ozone levels were associated with land-sea breeze recirculation (e.g., see figure 16).

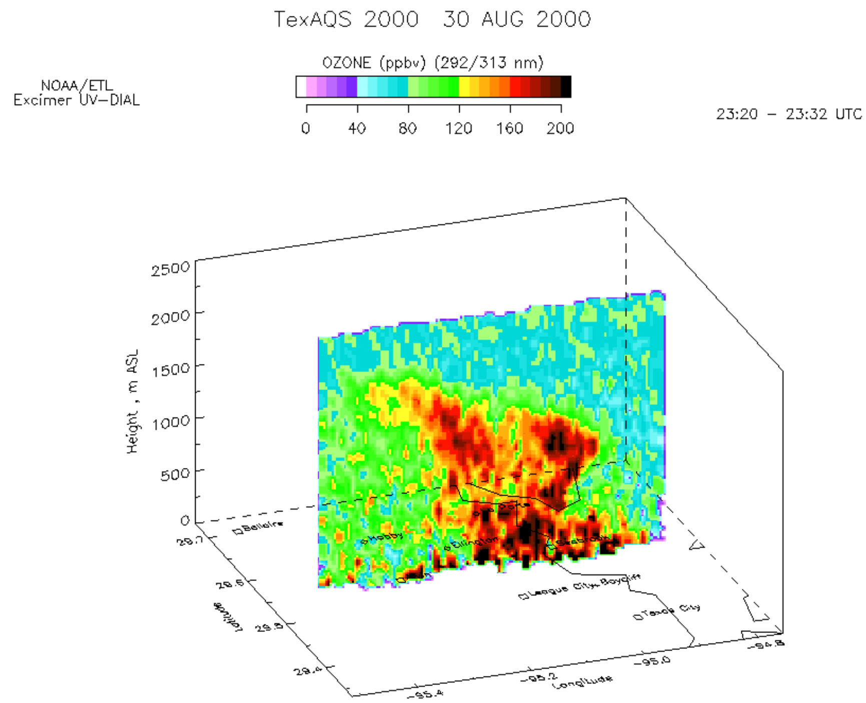


Figure 16. Ozone cross section from the NOAA ETL airborne LIDAR overlaid on a map of the Houston/Galveston Bay area. The highest ozone concentrations (> 200 ppb) are indicated by the areas colored in black. Note the rapid rise in the depth of the polluted layer as the sea/bay breeze bring the polluted air onshore.

- To determine the structure and productivity of urban and power plant plumes in the region. By flying multiple cross sections downwind of these sources, it will be possible to describe the areas influenced by these sources in three dimensions. In addition the total flux of ozone, and to a more limited extent aerosols, can be derived by combining data from the airborne LIDAR with the wind fields measured by an on-board Doppler lidar or derived from the network of radar wind profilers that will be deployed during the study.

- To characterize the variations in boundary layer height that occur as a result of synoptic weather patterns and land use. Previous studies[9] have shown that large

[9] Banta, R.M., C.J. Senff, A.B. White, M. Trainer, R.T. McNider, R.J. Valente, S.D. Mayor, R.J. Alvarez II, R.M. Hardesty, D.D. Parrish, and F.C. Fehsenfeld, Daytime buildup and nighttime transport of urban ozone in the boundary layer during a stagnation episode. *J. Geophys. Res.*, **103**, 22519-22544, 1998.

variations in the height of the mixed layer can occur as a result of changes in land use. These variations can have a significant effect on pollution levels and may affect venting to the free troposphere.

- To investigate the role of complex terrain in enhancing vertical mixing. Complex terrain can increase vertical mixing as a result of both differential heating and enhanced turbulence. The combined ozone/aerosol/wind profile measurements from a dual lidar aircraft deployment will permit examination of the relationship between winds, turbulence and ozone concentration over different types of terrain and over the ocean surface.

Expected Outcomes and Benefits

The proposed research will address significant information gaps and deliver sound science leading to an improved understanding of the processes that influence the air pollution levels to which the citizens of New England are exposed. More specifically, the proposed research program will advance the understanding of the following:

- The distribution of ozone and fine particles throughout the region.
- The relative importance of local and distant sources to measured pollution levels.
- The interaction between air quality and the weather, and ultimately climate.
- Levels of pollution exposure and deposition to sensitive ecosystems.

The study will also provide an educational opportunity for the students from UNH and Plymouth State College who participate in the measurement program and subsequent data analysis. These students are the future researchers and air-quality managers and policy makers who will be charged with the difficult task of protecting the quality of the air we all breathe. The opportunity to participate in this regional study will afford a unique opportunity to see the problem first hand.

The proposed effort will be an integral part of efforts to develop the tools needed to provide reliable air quality forecasts. The New England area will be an initial test bed for the proposed air quality forecasting system. The routine and intensive data sets will provide a means to evaluate alternative forecast approaches and fine-tune the chemical observing system that will be needed in a nationwide implementation. The study will also provide the opportunity to expand the existing undergraduate meteorological curriculum at UNH and Plymouth State to include training in air quality forecasting. These two institutions can play a leadership role while providing opportunities for their graduates in this exciting new area of atmospheric science.

The results of this research will be incorporated into ongoing efforts to provide policy relevant information in a timely and user-friendly manner to environmental decisionmakers. These assessment activities communicate new science to those charged with developing effective environmental policies for the Nation. As a result of this proposed program, the researchers in New Hampshire will be important new partners in these assessment endeavors.

Direct Payoffs for Decisionmakers

- Evaluation of skill of models used to develop air quality management strategies.
- Quantification of impacts of local and distant sources on New England air quality.
- Identification of the unique properties of New England aerosols that may impact public health.
- Identification of the role that forest emissions play in shaping New England Air Quality and how they can be impacted.

Coordination With Other Programs

The AIRMAP consortium will provide the primary resources and expertise needed to execute the New England Air Quality Study. However, the scope of the problem is large, both in terms of spatial extent and the complexity of the processes involved. Therefore, the study will be closely coordinated with a number of other research programs with similar goals to maximize the benefits of the planned research.

UNH's New England Integrated Sciences and Assessment - The basis of the New England Integrated Sciences and Assessment (NEISA) is the integration of scientific inquiry, climate related economic and human dimensions research, and the transformation and communication of relevant research results to meet specific needs. The ultimate goal is to build a basic understanding of human-environment interactions and provide information and responsive tools to decision makers. The NEISA will rely fundamentally upon the research efforts of AIRMAP. While the final definition of issues that will be addressed in the NEISA will depend upon information gathered from stakeholders and the public over the coming year, we expect to address three key climate-society issues in New England:

(1) The effect of air quality and extreme temperatures on human health;
(2) Extreme weather events and emergency management; and
(3) Climatic variation and New England's ski industry.

Intercontinental Transport and Chemical Transformation (ITCT) – The ITCT is being conducted under the auspices of the International Global Atmospheric Chemistry Project (IGAC). The goal of the program is to investigate intercontinental transport of anthropogenic pollution and to determine the chemical transformation that occurs during this transport. An important goal of this research is to estimate how the transport of this chemical from one continent can influence the air quality in another. The investigation will be initially focused in the Northern Hemisphere that contains most of the world landmasses, where most of the world's population resides, and where most of the anthropogenic pollution is generated. In many respects the New England region represents the starting point for pollution transport from North America to the North Atlantic and Europe. Thus a more complete quantification of the air quality and controlling processes in this region would provide a valuable input to the ITCT goals and objectives.

Potential Additional Collaborations – Discussions have been initiated with a number of additional potential collaborators who have a similar interest in the air quality of the New England region. These include:

- Intercontinental Chemical Transport Experiment (INTEX) - The NASA-sponsored INTEX field campaign is being proposed as an integrated field experiment that uses surface, airborne, and satellite platforms together with models to assess the impact of human induced emission on the composition and chemistry of the atmosphere in the Northern Hemisphere. This experiment will be conducted under ITCT/IGAC.

- Meteorological Service of Canada – This group is planning a series of intensive field campaigns to better understand the factors that control air quality in various parts of Canada. An intensive field campaign is tentatively planned for the Windsor Quebec City corridor for the 2004-2005 time period.
- Harvard Forest – This group has a long history of high-quality measurements at their research facility in central Massachusetts. Their presence in the region and their proximity to the AIRMAP network would make a collaboration beneficial.
- Whiteface Mountain – This site operated by SUNY-Albany also has a long history of research in a region adjacent to the proposed study region.
- DOE Atmospheric Chemistry Program – This focus of this program is similar to and, in many ways, complements, NOAA's Health of the Atmosphere program. NOAA and DOE have conducted a variety of intensive field campaigns together over the years.

Each of these programs has their own unique goals and objectives. Although different, these goals and objectives are linked, both in terms of the processes studied and the region of interest. A closer collaboration with benefit all and result in capabilities and perspectives that no single group could generate.