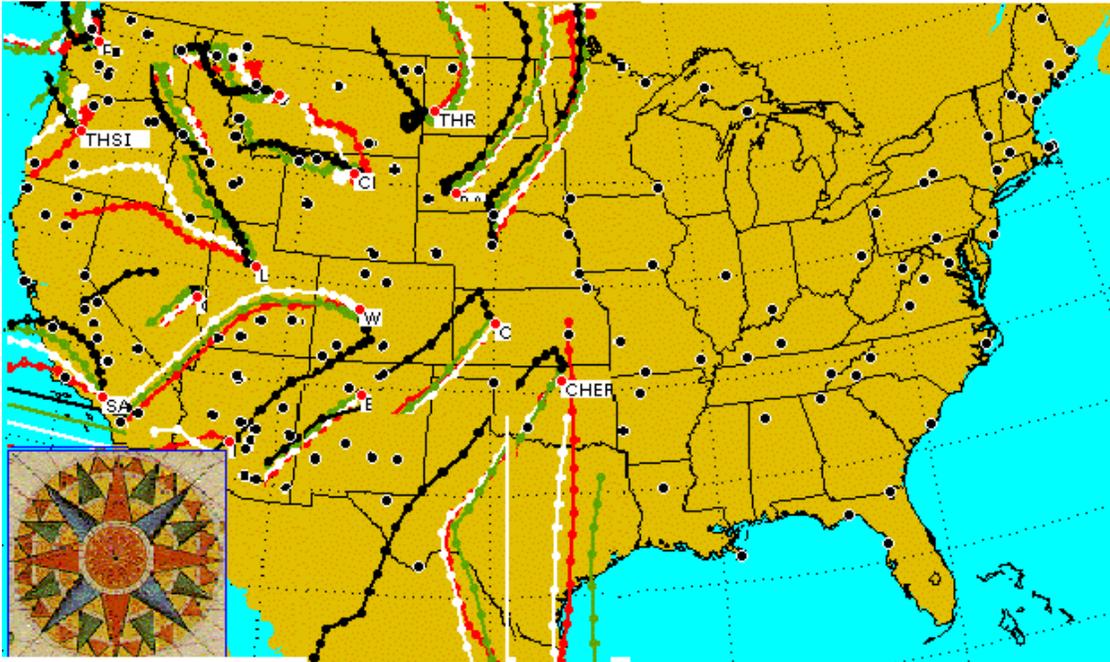


# Ozone Transport in the West

## An Exploratory Study



**Western States Air Resources Council**

**Zack Parsons**

**Steven Arnold**

**Colorado Department of Public Health and Environment**

**July, 2004**

## **Background**

Compliance with the 8-hour ozone standard may present new challenges to state, tribal and local governments in the West. The transport of precursor emissions and ozone over long distances is a documented phenomenon in the Eastern and Northeastern United States. Indications of several recent and past studies of western ozone events show that transport of emissions from as far away as Asia can impact the Western United States air quality. Studies on forest health, fire impacts on ozone levels, ozone trends, and back trajectory analysis to determine distant sources of ozone point to cases of long-range transport in the Western United States. High ozone episodes in Western urban cities can be augmented significantly by rural or urban upwind emissions.

These situations may call for new approaches to dealing with ozone in the West. Traditional control approaches for ozone focus on local emission sources, but upwind sources may need to be addressed. In addition, regulatory exclusions of high ozone due to natural or uncontrollable causes may need consideration so that an area would not receive a federal non-attainment designation for poor air quality. This paper explores past research related to Western ozone transport and provides groundwork for future research into the significance of regional transport of ozone in the West.

### **Ozone Formation**

Ozone is a colorless gas at normal atmospheric concentrations that is a natural part of the environment. In the upper atmosphere, ozone protects the earth from exposure to harmful ultraviolet rays. However, ozone can be formed in the lower atmosphere by natural processes or by man-made pollutants. Ground level ozone is a highly unstable gas that can be harmful to health, causing shortness of breath, asthma attacks and other health impacts. Lower atmosphere ozone is formed primarily by the reaction of oxides of nitrogen (NO<sub>x</sub>) and Volatile Organic Chemicals (VOCs) in the presence of moderate to intense sunlight. Based on adverse health impacts a National Ambient Air Quality Standard (NAAQS) was established by the United States Environmental Protection Agency (EPA) for ozone. Since there are relatively few anthropogenic (human caused) sources of ozone, control of ozone emissions is not effective in reducing ozone concentrations. Control of ozone is generally achieved by reducing the anthropogenic emissions of NO<sub>x</sub> and VOCs into the atmosphere. Solvents and combustion processes are two common sources of these pollutants.

### **Ozone Standards**

In 1997, the EPA adopted a new NAAQS for ozone based on the average of hourly ozone concentrations over an 8-hour period. The new standard for ozone is 0.08 ppm, averaged over an 8-hour span. This new NAAQS replaced the old standard, which was 0.12 ppm averaged over a 1-hour time period. Areas failing to meet these standards set by the EPA were declared “non-attainment areas” for ozone (Wierman, 2003). The Clean Air Act (CAA) defines non-attainment areas as “areas that either do not meet an ambient standard or contain certain sources of pollution that contribute to a violation of the standard in a nearby area” (Wierman, 2003).

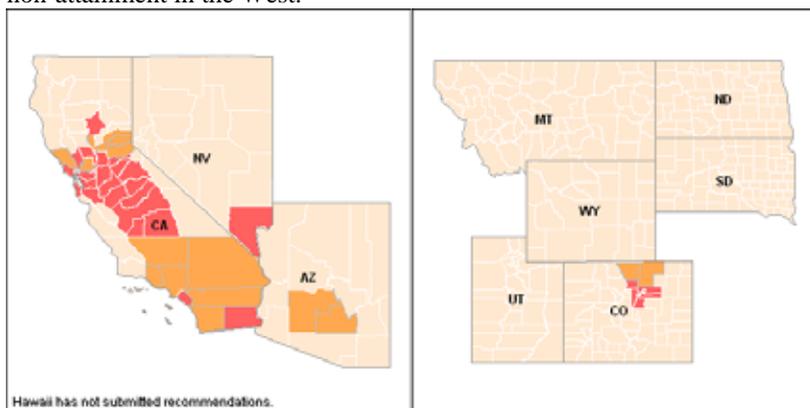
In 1990, several mid-Atlantic regions were designated as severe or serious non-attainment areas, in accordance with the 1990 CAA classification scheme, based on their 1-hour maximum concentrations. These areas of non-attainment included:

- 1) Charlotte, Raleigh-Durham, and Greensboro-Winston-Salem-Highpoint, NC;
- 2) Pittsburg, PA; and
- 3) Charleston, Greenbrier County, Huntington-Ashland, and Parkersburg, WV (Wierman, 2003).

Under the 1-hour standard, many states adopted State Implementation Plans (SIPs) with strict NO<sub>x</sub> and VOCs emission controls to comply with the 1-hour standard set by the EPA. Since then, there have been vast improvements in air quality and, using data from today, none of the areas noted above are currently labeled as in the severe or serious non-attainment classification (Wierman, 2003). However, since implementation of the new 8-hour standard, many states are now in non-attainment more days out of the year than previously under the old 1-hour standard.

One example showing how the 8-hour standard differs from the 1-hour standard is the new non-attainment classification of Shenandoah National Park in Virginia. This park is a designated “Class I” area and labeled as a pristine site. Class I is a designation in the Clean Air Act given to certain national parks and wilderness areas of significant size where visibility is considered an important value. Most of the ozone affecting Shenandoah National Park comes from long-range transport from sources in the Ohio River Valley (Wierman, 2003).

There are currently four states in the West with areas that do not comply with the 8-hour standard, including California, Nevada, Arizona, and Colorado. Figure 1 contains a map showing areas classified as non-attainment in the West.



**Figure 1- Eight Hour Ozone Non-attainment Areas of the West based on 2001 to 2003 data.**

Areas that do not comply with the 8-hour standard, but do not want to be designated as non-attainment, were allowed to opt into an Early Action Compact (EAC) prior to December 2002. An EAC “commits an area to steps that will help reduce 8-hour ozone levels faster than required by the CAA, in hopes air quality will improve and an 8-hour non-attainment designation can be avoided” (Wierman, 2003). Currently there are 35 areas using EACs, including Denver and Farmington, New Mexico. Areas using this process must comply with the 8-hour standard by December 31, 2007.

As with the one-hour standard, some areas are impacted by long-range transport of ozone or ozone precursors resulting in high 8-hour ozone in rural or semi-rural areas. Many states have found that air coming into an area appears to increase background levels to half or more of the 8-hour ozone standard. With the addition of sub-regional and local ozone production, long-range transport can lead to high levels of ozone and even non-attainment classifications.

### **Eastern Ozone Transport**

In the Eastern United States, the formation and transport of ozone over long distances is a well-studied and well-documented phenomenon leading to control programs throughout the Northeast and Southeast. These control programs are often more regional in scope, with local controls only acting as enhancements. Eastern states and local governments have found that NO<sub>x</sub> emissions from regional power plants and large industrial combustion sources in the Midwest and Southeast are being transported to the Northeast, thus contributing to non-attainment classifications in these areas.

Long-range transport is caused by a number of factors. The main factor in the East is wind flow and direction. In a paper prepared by System Applications International Inc., it was found that “moderate to high wind speeds were classified as having a moderate to high potential for a contribution from transport” (Douglas and Hudischewskyj, 1997). During an episode of high ozone with moderate to high winds pollution from the Midwest and Southeast is taken by airflow streams to the Northeast, causing high ozone episodes for this region. This has been displayed using back trajectory analysis -- a computer model that accounts for wind patterns -- by reconstructing air paths from the Midwest and Southeast, where heavy NO<sub>x</sub> emissions occur, to downwind ozone monitoring sites in the Northeast.

To address the problem of ozone transport the Clean Air Act Amendments (CAAA) established the Ozone Transport Region (OTR) in 1990. The OTR was comprised of 11 states in the Northeast, from the Washington, D.C. metropolitan area to Maine. This was the first attempt to address long-range transport of ozone. The OTR led to the formation of the Ozone Transport Assessment Group (OTAG), an organization created by the EPA in 1995 to help with the problems surrounding long-range transport of ozone to the Northeastern United States. OTAG conducted research and modeling of the phenomenon and concluded long-range transport of ozone from the Midwest and Southeast was a significant factor for the OTR in not achieving attainment of the NAAQS for ozone (Yarbrough 2000). The Northeast States for Coordinated Air Use Management (NESCAUM) also did a study that concluded NO<sub>x</sub> in the range of 305,000 to 686,000 ton per year was transported from the Midwest to the Northeast (Moomaw, 1998).

This information led the US EPA to create a new State Implementation Plan (SIP) call that required 22 states in the East and Washington DC to submit SIP revisions by September 30, 1999. This SIP created a new program, called a budget and trade program, for NOx emissions. This budget and trade program gave each NOx source an allotment of a fixed number of tons of NOx it could emit per year. If the source went over its allowable limit it would then have to buy or obtain emission allowances from other sources. This program provided an overall cap on all NOx emissions in the region. It provided incentives to sources reducing NOx emissions, allowing their NOx allotment to increase (Yarbrough 2000). This also led to sources looking at low-NOx alternatives such as natural gas combustion. These measures, taken by NOx emitting sources and the EPA, are helping reduce ozone levels in the Northeast. Experts project a 43 percent reduction in NOx emissions in this region by 2007 compared to the 1990 emission levels (Ozone Transport Commission, 1998).

**Western Ozone Transport**

Long-range transport of ozone and precursors has become a concern in the West. Unlike the East, Western ozone was typically thought to be isolated to a local area. With the introduction of the new 8-hour standard, five Western States were found to have non-attainment areas. (Since Texas is considered part of the Eastern transport issue this report focuses on California, Nevada, Colorado, and Arizona.) These Western states, like the Eastern states, found that ozone levels are impacted by transport from distant areas along with local impact. Recent modeling for the Denver Early Action Compact indicated transported ozone significantly impacted the final ozone concentration recorded in the Denver region (Regional Air Quality Council, 2004).

**Asian Impacts**

One of the impacts affecting ozone levels in Western states is the long-range transport of pollutants from countries in Eastern Asia. Several research studies demonstrated NOx, hydrocarbons (HC), and other air pollutant emissions significantly impact the background levels of ozone measured in Western North America (Schwarzhoff, 2003).

Since the mid 1980s Eastern Asia has seen increasing energy consumption, fossil fuel combustions, and NOx and HC emissions. This, coupled with a minimal set of pollutant controls for these countries, has led to heightened pollution and transport levels. Studies by Akimoto and Narita (1994) and Streets et al. (2001) found that during the past two decades, NOx emissions in Asia have increased at a rate of 4 to 6 percent per year. Ozone concentrations in these countries also had a steady increase of 2.5 percent per year from 1989 to 1997 (Lee et al., 1998).

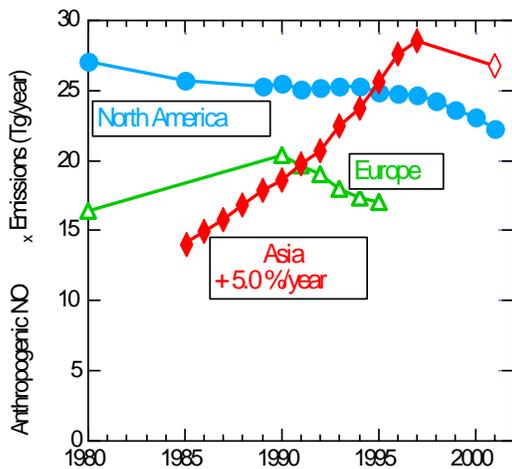
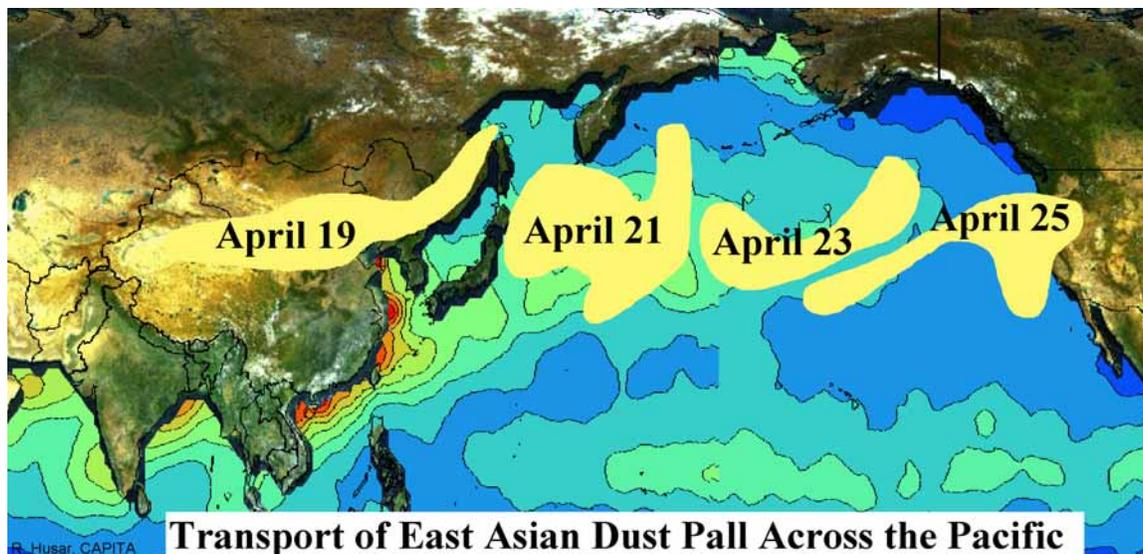


Figure 2- Graph showing NOx increase in Asia

Due to these increases in Asian emissions, ozone in air arriving at the West Coast of the United States from Asia has increased by approximately 10 ppbv. This is approximately a 30 percent increase from the mid 1980s to the present (Jaffe et al., 2003). An increase in background concentrations of 25-55

ppbv of O<sub>3</sub> and NO<sub>y</sub> on the West Coast was found in studies by Hirsch et al. 1996; Altshiller and Lefohn 1996; and Logan 1989. Most of these increases were due to transport from Eastern Asia.

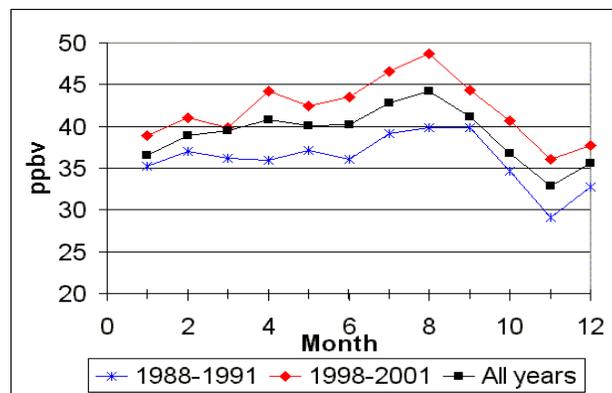
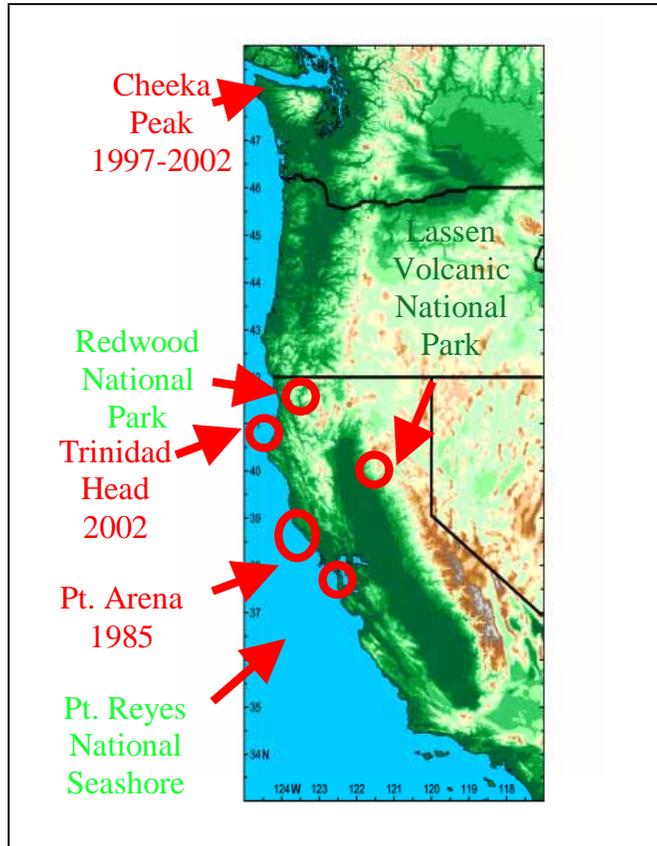
A well-documented example of inter-continental transport of pollutants occurred in April 1998, when a major windstorm impacted Western China and transported huge dust clouds across the Pacific Ocean affecting much of the Northwestern United States (Schwarzhoff, 2003). Figure 3 depicts the progression of transported dust over seven days resulting in high fine particulate levels on the West coast and later, further inland. While this episode specifically focused on tracking particulate matter from Asian sources, it demonstrates a clear situation where significant amounts of pollutants are transported from Asia to the Western United States leading to appreciable increases in pollution levels in this far downwind region.



**Figure 3- Transport of dust over pacific to United States**

Several studies found that different wind patterns affect the flow and transportation of pollutants. These studies indicate that long-range transport of ozone is most significant between April and June (Jacob et al., 1999). “Asian outflow to the Pacific is particularly strong in spring because of frequent cyclonic activity and associated warm conveyor belts (WCBs) that sweep across East Asia and lift pollution to the free troposphere and into the westerlies” (Stohl, 2001; Liu et al., 2003; Miyazaki et al., 2003). These winds take the increasing NO<sub>x</sub>, HC, O<sub>3</sub>, and other pollutants from Asian countries, to the Western United States, causing background levels of ozone to increase. Observations from aircraft used by the Photochemical Ozone Budget of the Eastern North Pacific Atmosphere (PHOBEA) measured pollution plumes as large as 27 ppbv over the United States West Coast that originated from Asia (Jaffe et al., 2002; Price et al., 2004).

Data taken from the United States National Park Service (NPS) at 6 locations near the West Coast show “a constant, statistically significant, positive trend in background O<sub>3</sub>” (Jaffe et al., 2004) during the months of April through August. The data is from six sites known to be free of large influences from local emissions. The sites include Lassen Volcanic National Park, Point Reyes National Park, Redwood National Park, Cheeka Peak, WA; Point Arena, CA; and Trinidad Head, CA.



**Figure 4- Ozone observations 1988-2001 from N.P.S. site at Lassen N.P.**  
 (Analysis by Dan Jaffe, University of Washington, Bothell)

The increasing trends of ozone concentrations in Asia that have been associated with increases of background ozone and NO<sub>x</sub> levels in the Western United States may lead to elevated ozone concentrations in excess of the NAAQS.

**Forest Fire Impacts**

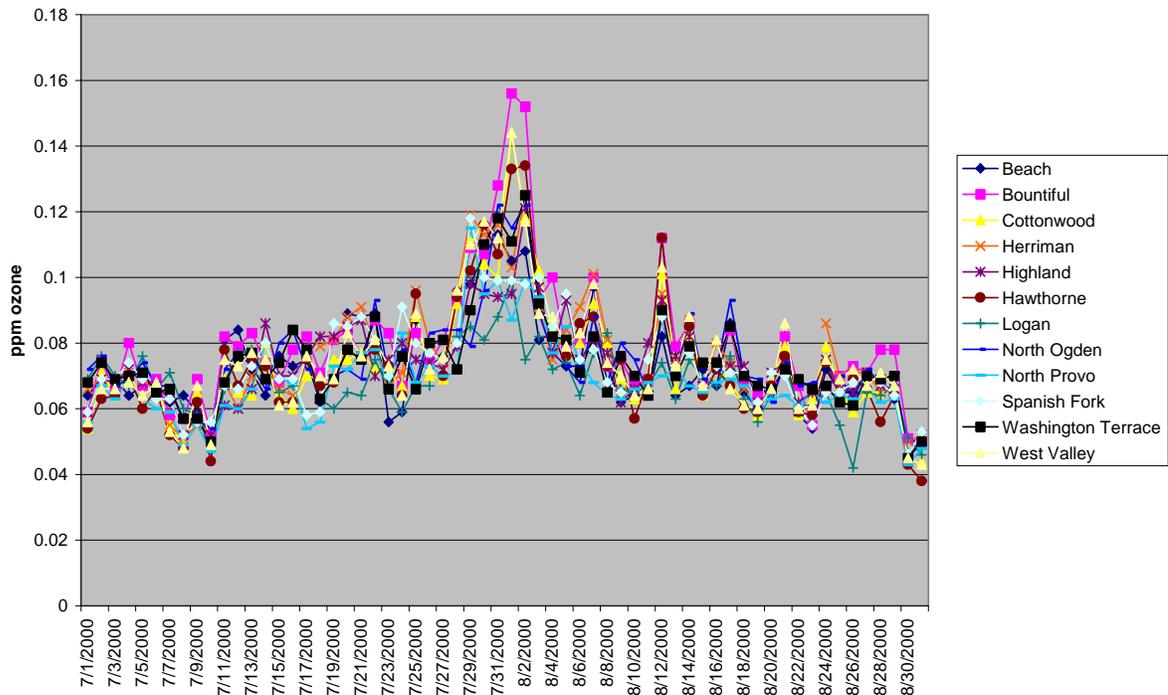
Another contributor on high ozone days in the West that could lead to non-attainment of ozone standards is forest fires. Smoke within these biomass fires contain high levels of NO<sub>x</sub> and HC, which combines with sunlight resulting in the formation of ozone. This, along with other ozone pollutant

precursors, can then be transported into urban areas resulting in increased background ozone levels and the formation of more ozone (Hall, 2003).

In the summer of 1995, there were several large forest fires located in Northwest Canada. During this time, several states in the Southeastern United States and along the Eastern Seaboard monitored increased levels of ozone and other pollutants. One study done by the American Association for the Advancement of Science indicated, “forest fires influenced the buildup of ozone episodes in the Southeastern United States by increasing background air pollution” (Trainer & Wotawa, 2000). The study also discovered “Regional background ozone concentrations were elevated by 10 to 20 ppb” during these forest fire episodes (Trainer & Wotawa, 2000). After reviewing the data from these studies, the EPA concluded smoke could increase ozone precursors and transport ozone. The EPA also concluded fire is a contributing factor on some high ozone days. The EPA incorporated the relationship between ozone formation and forest fires into their “Guideline on the Identification and Use of Air Quality Data Affected by Exceptional Events.” Several States used this guideline to receive exemptions from high ozone readings where large-scale wildfire emissions influenced downwind readings. The exemptions are important in avoiding a non-attainment designation for ozone.

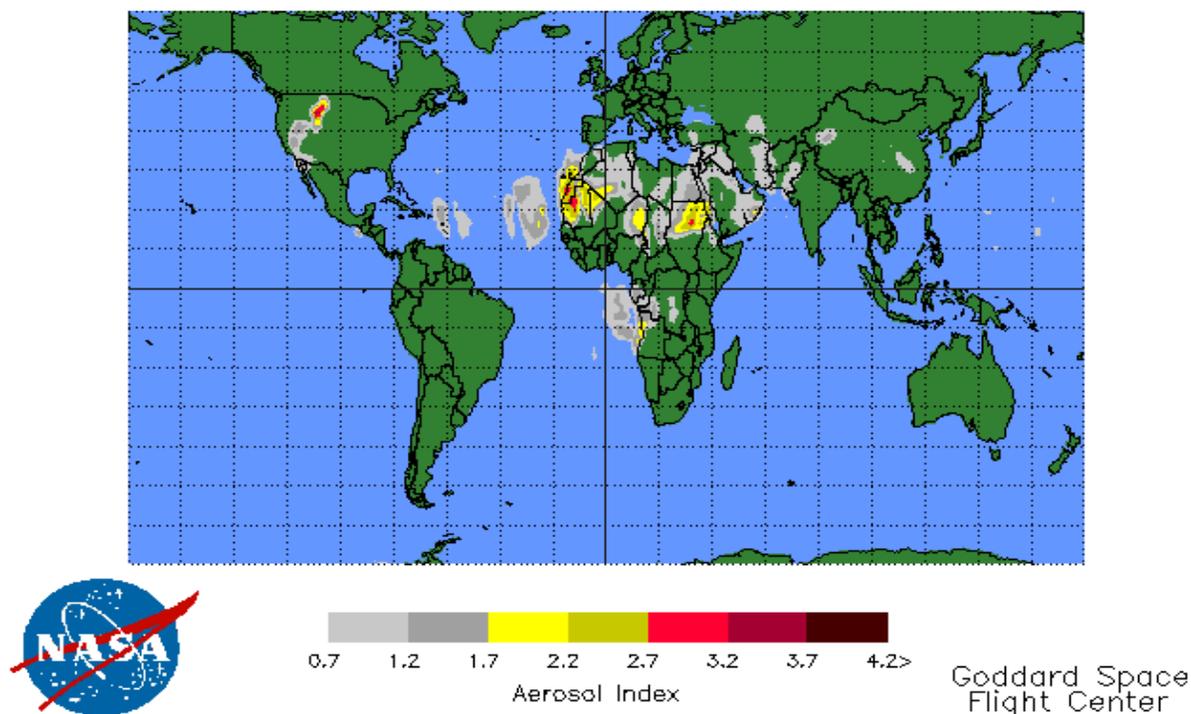
Another example of increased ozone due to forest fires is a one-week episode in Northern Utah, where ozone concentrations for the entire monitoring network were elevated between July 28 and August 3, 2000. Unusually high levels of visible smoke and haze in the area also accompanied this episode (Utah Division of Air Quality, 2001). This, along with monitoring data from previous years showing improvements in the 1-hour ozone levels helped provide proof that fires had a significant impact in increased levels of ozone during this event (Delaney, 2004).

**Maximum Daily 1- Hour Ozone Measurements, July - August, 2000**



**Figure 5- Utah daily maximum 1-hour ozone measurements July 28 thru August 3<sup>rd</sup>, 2000. .**

Earth Probe TOMS Aerosol Index  
on July 30, 2000

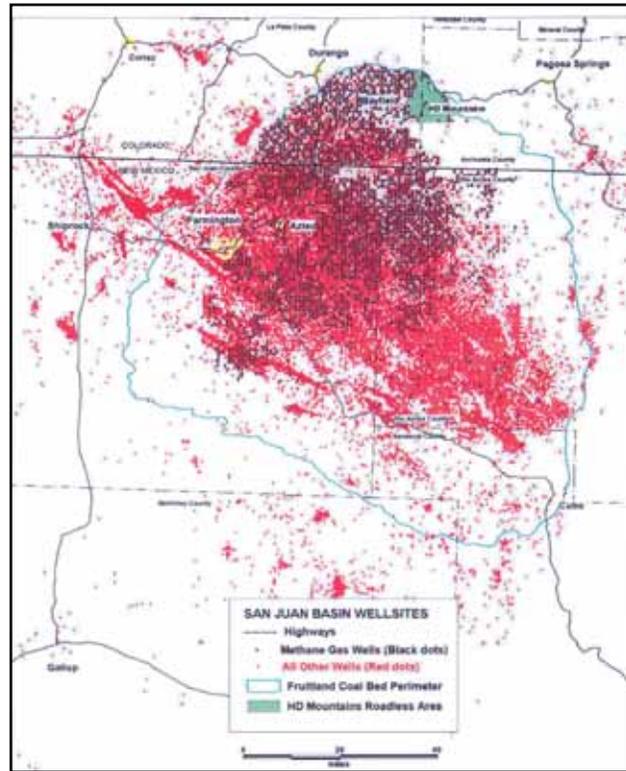


**Figure 6- Data taken from TOMS and GOES satellites also show a large aerosol plume across most of Utah and Nevada during this period.**

Figures 4 and 5 contain data Utah presented to the EPA as partial substantiation of the impacts of transported precursors and ozone into the Salt Lake City area during this high ozone forest fire episode in 2000. The EPA found that smoke from these forest fires had been a large contributor to the increased ozone levels during this one week. These dates were flagged by the EPA as exceptional events and excluded from the Utah ozone averages. The EPA has recognized similar events in Florida and Texas due to forest fires and given exclusions in both these cases to avoid non-attainment designations.

#### **Oil and Gas Development**

Other contributing factors to ozone formation are large emissions of NO<sub>x</sub> and HC from Coal Bed Methane (CBM) wells. Currently in the northern San Juan Basin, there are approximately 20,000 CBM wells in New Mexico and 2,500 wells in Colorado, with 10,000 more proposed for oil and gas development in New Mexico and 1,000 more proposed for Colorado (RTP Environmental, 2004).



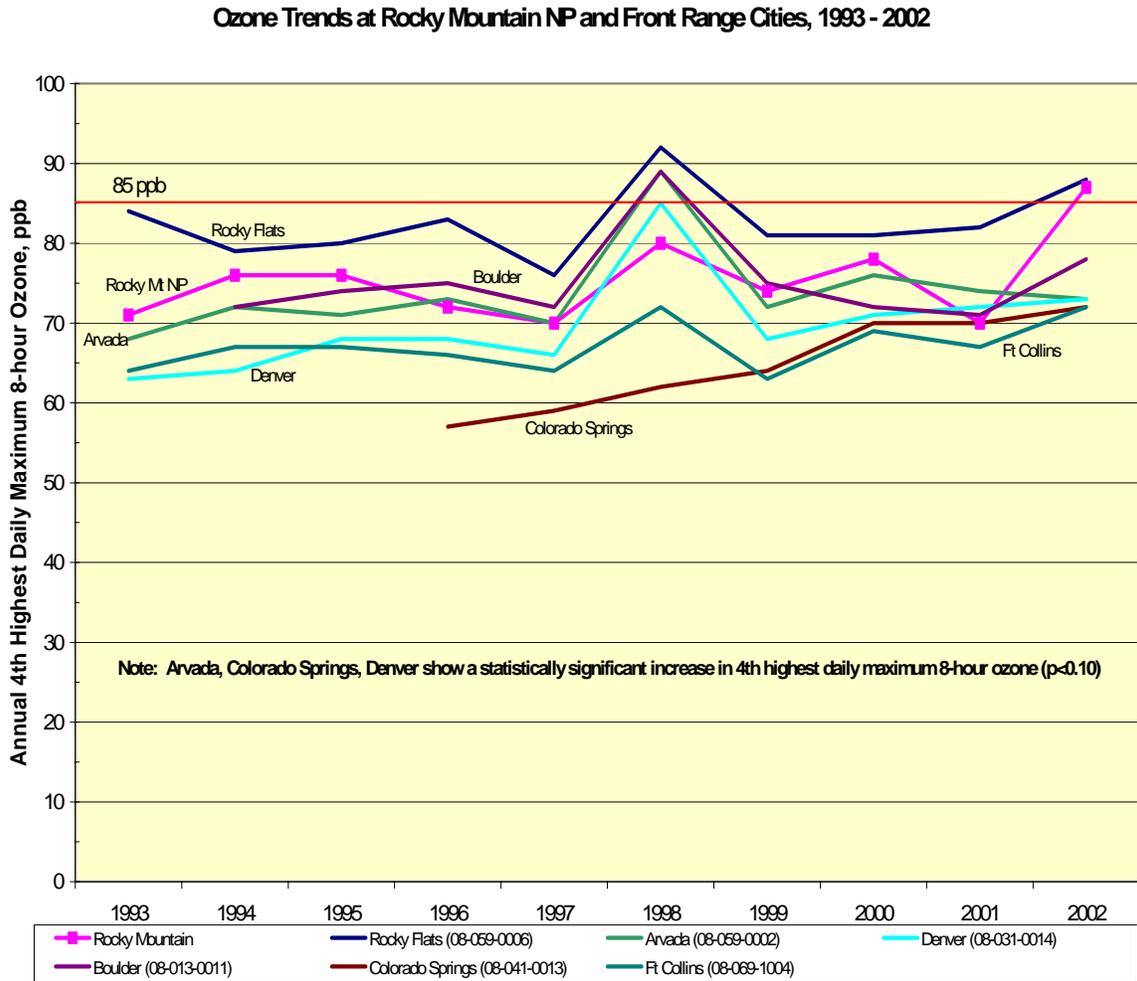
**Figure 7- Existing and proposed oil and gas wells in the San Juan Basin.**

Key issues concerning these wells, and the possible development of additional wells, are: the potential impacts to ozone and other pollutant standards, consumption of Prevention of Significant Deterioration (PSD) increments, Hazardous Air Pollutant (HAP) concentrations, visibility degradation, and atmospheric particulate deposition to sensitive lakes (RTP Environmental, 2004). Two nearby sensitive areas are Mesa Verde National Park and Weminuche Wilderness Class I Areas where adverse visibility impacts have already been noted. Emissions from these wells have been suggested as one source of the air pollution impacts in the area. Although emission statistics data have not been fully studied and recorded, it is obvious that sources from oil and gas development need to be accounted for when developing ozone plans.

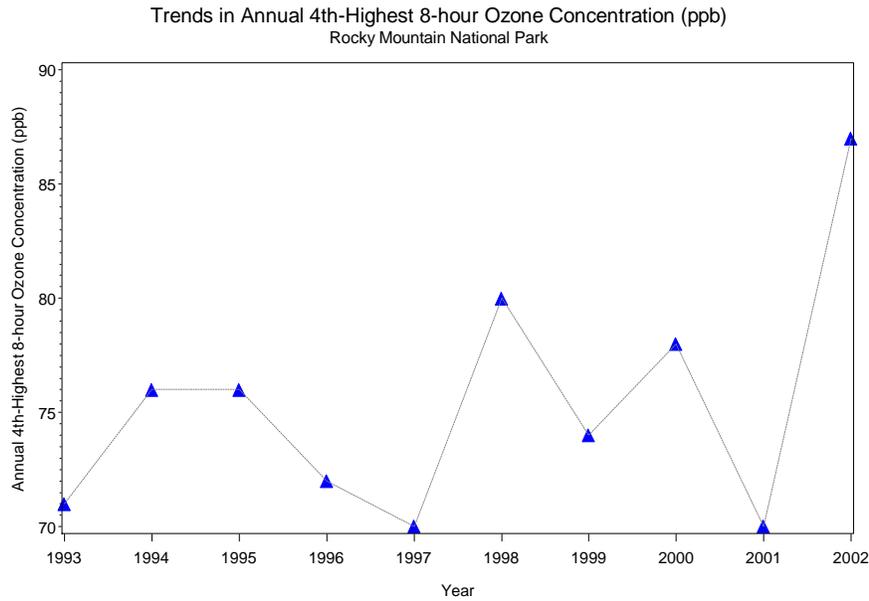
**Damage to Pine Trees** Ozone transport to rural Western forests have also been associated with damage to pine trees. Ozone concentrations as low as 60 ppb can cause injury to foliage, a decrease in growth, and lead to increased tree mortality and changes in ecosystem composition (Bohm et al., 1995). In a study done on ozone impact on Western forests, 63 sites in or near Western forests were studied for ozone concentrations. From these 63 sites, eight classes of ozone regimes were identified from the characteristic patterns, based on how ozone was formed and transported. These eight classes include; Large-urban, Medium-urban, Small-urban, Urban-downwind-urban, Urban-transport, Rural, Rural-remote, and Remote (Bohm et al., 1995). From these areas and the characteristics shown, researchers concluded, “many sites in or near Western forests receive ozone that has been transported from urban sites some distance away” (Bohm et al., 1995).

In the West, the NPS administers more than 130 national parks, national monuments, and other lands. Of these 130 areas, 36 are Class I air quality areas (Vimont, 2004). These areas encompass a wide variety of ecosystems and resources from high alpine tundra to deserts (Vimont, 2004). Studies conducted by the NPS show trends in ozone have been increasing in most national parks from 1993 to 2002. Ozone levels in parks are higher, in some cases, than levels in urban areas during similar ozone events. All parks have shown some degree of injury to foliage of sensitive species including aspens and ponderosa pines. When ponderosa pines are exposed to severe ozone they may only retain needles for a single year as opposed to up to five years for a healthy pine (Stolte 1996). Injured foliage from ozone also increases

dead fuels, which increases the chances of forest fires (Diem 2003). One park of great concern is Rocky Mountain National Park (RMNP). This graph shows the increasing trends in ozone at Rocky Mountain National Park and how this trend compares to surrounding urban areas.



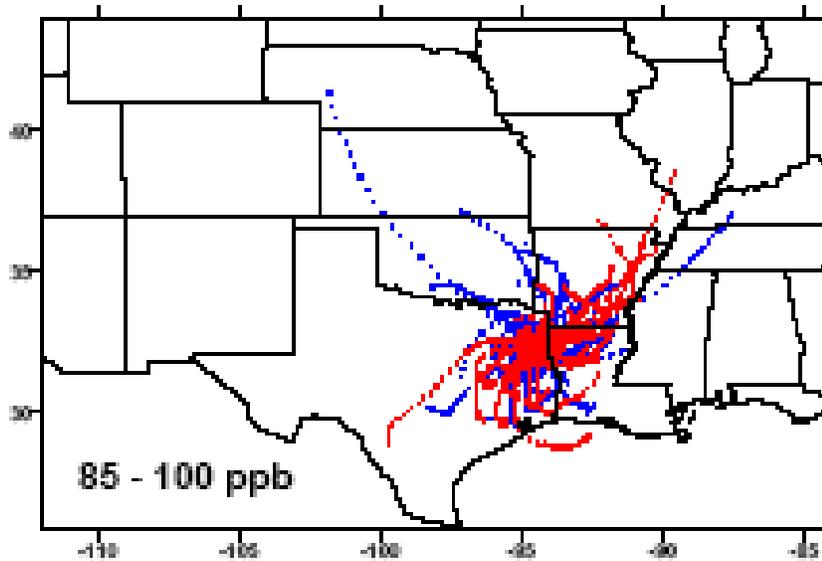
**Figure 8- Trends in ozone in Denver areas Front Range areas.**



**Figure 9- Trends in ozone at Rocky Mountain National Park**

**Tracking Ozone Transport**

One way to track ozone transport is by using back trajectory analysis. Back trajectory analyses are computer models that analyze data from past weather forecasting models to predict how air moves and arrives at a fixed destination (Yarwood et al., 2000). The National Oceanic and Atmospheric Administration (NOAA) provides a modeling tool known as the HYSPLIT model, which calculates back trajectories. Another tool that calculates back trajectories, VIEWS, provides a similar product using different assumptions and weather models. These tools can be used as indicators as to whether or not a high ozone level could be attributed to ozone transport from other areas (Yarwood et al., 2000). A back trajectory study on high ozone events in East Texas from 1995 to 1999 concluded 8-hour ozone averages above 85 ppm could result from air transported from 200 km away. The trajectory showed that most airflow was from the east-northeast and south-southwest during these high ozone periods. (Yarwood et al., 2000).

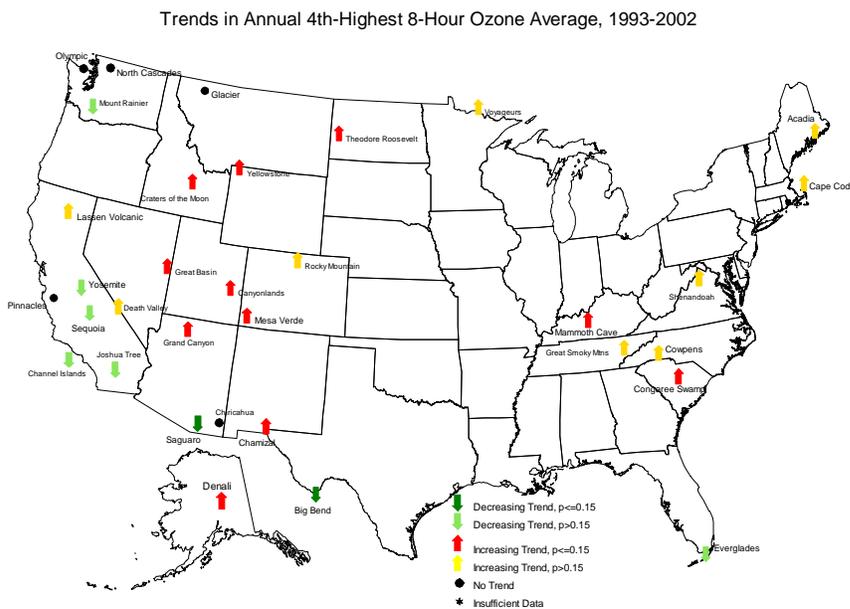


**Figure 10- Ozone back trajectory plots of ozone events exceeding 85 ppb in Houston Texas. Dotted lines indicate 1-hour air masses tracked back from the ozone event.**

Another study on this area from 2002 to 2003, using back trajectory analysis also proved that high ozone days are associated with winds from the east-northeast or south-southwest (Stoeckenius et al., 2004).

During the summer of 1998 Las Vegas experienced 11 days where it exceeded the 8-hour NAAQS set for ozone. Using the NOAA HYSPLIT tool, the back trajectory suggests most high ozone episodes may have originated from populated areas of Southern California, particularly on June 24 (Stoeckenius et al., 2004). Backing up these results are data from ozone monitors between Las Vegas and areas of heavily populated Southern California, which show that on the June 22 ozone concentrations at these sites are relatively low. However, on June 23 and 24, levels at all sites increased to 8-hour averages above 0.08 ppm before decreasing on June 25 to lower 8-hour averages (Stoeckenius et al., 2004). These studies indicate back trajectory analysis may be a useful tool for determining the causes of high ozone episodes. However, the back trajectory process highly simplifies the pattern of wind, ignoring such factors as mixing and wind shear and may produce suspect results. Tools used to calculate back trajectories can be found at <http://www.arl.noaa.gov/ready/hysplit4.html> and <http://vista.cira.colostate.edu/views>.

The contribution of transported ozone to high urban levels in the Western United States is an issue that needs more study. The Colorado Front Range is one area with significant increases in ozone over the past several years at remote sites. This map shows that other areas across the West are also showing increased levels of ozone.



**Figure 11- Other areas in the West showing increased levels of ozone**

Attainment of the 8-hour ozone standard might be more difficult than attaining the old 1-hour standard because transported ozone and ozone precursors have a much greater chance to impact an area downwind in this longer timeframe than for the shorter 1-hour maximum. Transported ozone levels from upwind sources can be quite high before reaching an area. Sub-regional and local emissions and processes only add an increment to the problem by augmenting these concentrations. Traditional planning in the West has attempted to resolve ozone problems by only dealing with local strategies and Federal controls. To meet the 8-hour standard, it may be necessary to consider upwind sources to gain control of the problem or to exclude events beyond state and local control.