INTERAGENCY MONITORING OF PROTECTED VISUAL ENVIRONMENTS

IMPROVE

3rd Quarter 2004 | The IMPROVE Newsletter | Volume 13 / Number 3

Monitoring update

Feature Article: BRAVO study reveals causes of haze at Big Bend NP, Page 4

Network operation status

The IMPROVE (**I**nteragency **M**onitoring of **Pro**tected **V**isual **E**nvironments) Program consists of 110 aerosol visibility monitoring sites selected to provide regionally representative coverage and data for all 156 Class I federally protected areas. Additional instrumentation that operates according to IMPROVE protocol in support of the program includes:

- 57 aerosol samplers
- 16 transmissometers
- 43 nephelometers
- 13 film or digital camera systems
- 47 Web camera systems
- 3 interpretive displays

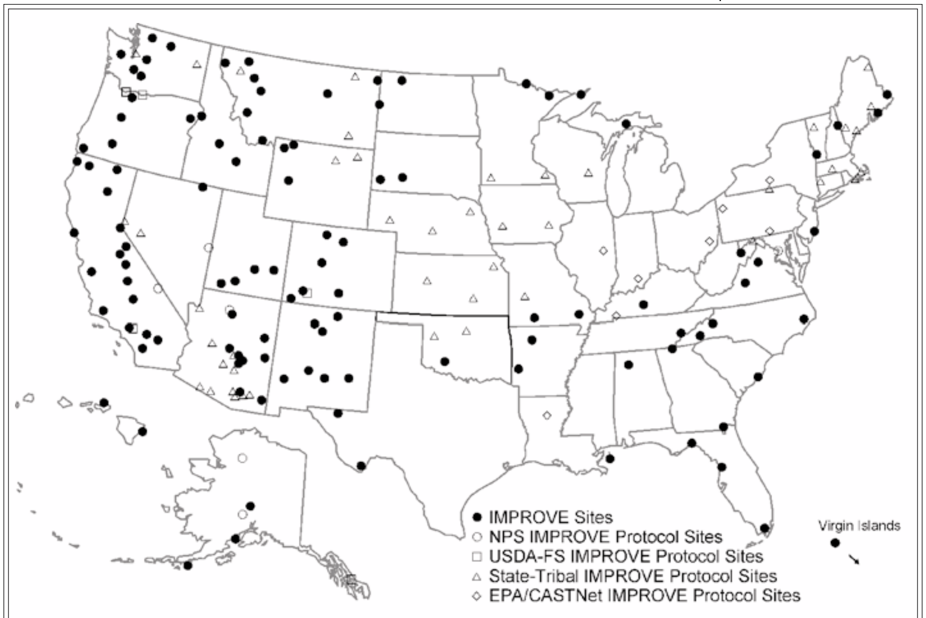
IMPROVE Program participants are listed on page 8. Federal land managers, states, tribes, and other agencies operate supporting instrumentation at monitoring sites as presented in the map below. Preliminary data collection statistics for the 3rd Quarter 2004 (July, August, and September) are:

- Aerosol (channel A only) 96% collection
- Aerosol (all modules) 94% completeness
- Optical (transmissometer) 89% collection
- Optical (nephelometer) 96% collection
- Scene (photographic) 97% collection

Instrumentation added to the networks this quarter includes aerosol samplers at Shamrock Mines, CO, (installed July, sponsored by the US-Forest Service) and two temporary samplers at New York City, NY, and Fresno, CA, (for comparison with the EPA's Speciation Trends Network samplers located in those areas).

A new aerosol site at Zion Canyon, UT, was installed in February 2003. Both the existing Zion National Park site and the new Zion Canyon site were operated for over a year to obtain collocated comparison data. The Zion National Park site was removed during 3rd Quarter 2004.

In mid-September, Hurricane Ivan made landfall along the U.S. Gulf Coast and traveled northward through the Appalachian Mountains. This region is home to a number of IMPROVE sampling sites. Many sites escaped unscathed, and three sites lost samples due to power outages only on a single day, September 18: Shining Rock, NC; Linville Gorge, NC; and Cohutta, GA. However, the site at Breton, LA, was severely damaged. Floodwaters reached waist high or higher, and the electronic components of the IMPROVE sampler were ruined. Electrical power was out at this site as well. A new sampler is scheduled to be installed and power restored to the site later this month.



IMPROVE and IMPROVE Protocol Sites
3rd Quarter 2004

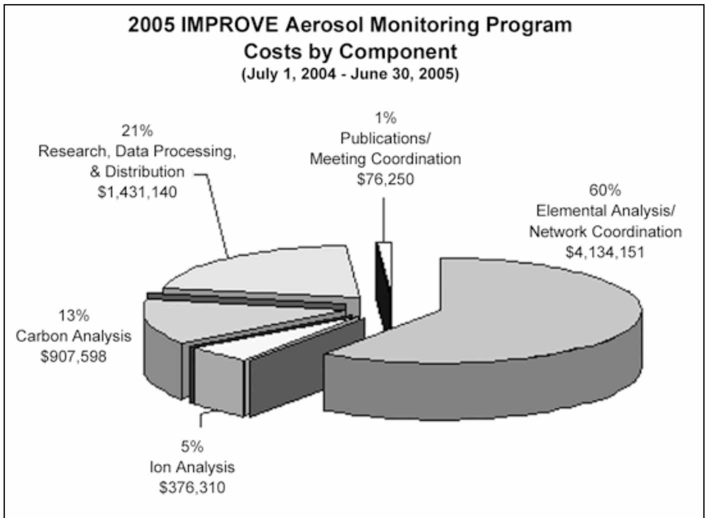
Monitoring update continued on page 2....

Visibility news

IMPROVE 2005 aerosol monitoring budget

The total IMPROVE aerosol monitoring program budget for IMPROVE Year 2005 (July 1, 2004 - June 30, 2005) is $6,925,449. Of this amount, the EPA has provided $5,899,355 or 85%, used exclusively for the components shown in the graphic below.

The cost to operate and maintain an IMPROVE aerosol monitoring site for one year is $34,517 (excluding operator salary and procurement of new or replacement equipment). The IMPROVE aerosol monitoring program and federal land managers (FLMs) fund the IMPROVE network. Operator salaries, optical and scene monitoring equipment, and Web cameras are funded separately from the IMPROVE aerosol monitoring program.



For more information contact David Maxwell at the National Park Service Air Resources Division. Telephone: 303/969-2810. Fax: 303/969-2822. E-mail: david_maxwell@nps.gov.

Monitoring update *continued from page 1 ....*

Data availability status

Data are available on the IMPROVE Web site, at *http://vista.cira.colostate.edu/improve/Data/data.htm*. IMPROVE and other haze related data are also available on the VIEWS Web site, at *http://vista.cira.colostate.edu/views*. Aerosol data are available through February 2004. Transmissometer data are available through December 2003 and nephelometer data are available through June 2004. Photographic slide spectrums are also available on the IMPROVE Web site, under *Data*. Real-time Web camera displays are available on a variety of agency-supported Web sites.

Monitoring update *continued on page 3....*

Digital imaging processing and analysis techniques being developed

Similar to historical quantitative validation of 35mm slides, techniques to extract air quality metrics from pixel data in high resolution digital images are now being developed. Several metrics, including target/sky contrast and color saturation, are being evaluated and compared to collocated visibility monitoring instrumentation, to determine if digital images can be used to estimate visual air quality. If good estimates can be obtained, they may be used as a surrogate for measured optical data.

Estimating air quality metrics is first accomplished through digital image evaluation, which includes three steps:

1) Image registration - Each image must be registered to account for camera movement. The registration process entails creating a black and white image of the registration region so that a binary comparison to a base/reference registration image can be done. By doing this, clouds, shading, and other color variances can be eliminated.

2) Clear sky identification - Each image is tested for cloud-free, clear sky conditions. These tests are designed to determine which images are least affected by clouds.

3) Image metric extraction - Each image is evaluated for metrics that can be related to measured visibility conditions.

Scientists at Air Resource Specialists, Inc. evaluated hundreds of images using these techniques. The target/sky contrast metric correlated well with measured extinction, but it includes the same uncertainties associated with 35mm slides. The color saturation metric involves converting the images from RGB (red, green, blue) to HIS (hue, intensity, saturation). The color saturation channel is then used as the image metric because less saturated colors tend to occur during lower visibility conditions. Initial results show a relationship between color saturation and measured extinction, though there is significant variability. The color saturation metric is being investigated in more detail, along with other, more advanced metrics.

For more information contact Scott Cismoski at Air Resource Specialists, Inc. Telephone: 970/484-7941. E-mail: scismoski@air-resource.com.

Visibility news *continued on page 7....*

Monitoring Site Assistance:

Aerosol sites: contact University of California-Davis telephone: 530/752-7119 (Pacific time)

Optical/Scene sites: contact Air Resource Specialists, Inc. telephone: 970/484-7941 (Mountain time)

Monitoring update *continued from page 2 ....*

Outstanding sites

Data collection begins with those who operate, service, and maintain monitoring instrumentation. IMPROVE managers and contractors thank all site operators for their efforts in caring for IMPROVE and IMPROVE Protocol networks. Sites that achieved 100% data collection for 3rd Quarter 2004 are:

Aerosol

Acadia	Glacier	Phoenix
Addison Pinnacle	Grand Canyon	Pinnacles
Ambler	Great Basin	Pittsburgh
Arendtsville	Great Gulf	Point Reyes
Atlanta	Great River Bluffs	Presque Isle
Badlands	Great San Dunes	Proctor Research Center
Baltimore	Great Smoky Mountains	Quaker City
Big Bend	Hawaii Volcanoes	Quabbin Reservoir
Birmingham	Hercules-Glades	Redwood
Bliss	Hillside	Rocky Mountain
Blue Mounds	Hoover	Saguaro West
Bondville	Houston	San Gorgonio
Bosque del Apache	Isle Royale	Seattle
Bridger	James River	Seney
Bridgton	Jarbidge	Sequoia
Cabinet Mountains	Joshua Tree	Shamrock Mine
Caney Creek	Kalmiopsis	Snoqualmie Pass
Canyonlands	Lake Seguma	Starkey
Cape Cod	Lassen Volcanic	Sula
Cape Romain	Lostwood	Sycamore Canyon
Casco Bay	Mammoth Cave	Theodore Roosevelt
Cedar Bluff	Martha's Vineyard	Three Sisters
Cherokee	Meadview	Tonto
Chicago	Medicine Lake	Tuxedni
Cloud Peak	Mohawk Mountain	Upper Buffalo
Columbia Gorge East	Monture	Viking Lake
Connecticut Hill	Moosehorn	Virgin Islands
Dolly Sods	Mount Hood	Voyageurs
Douglas	Mount Rainier	Walker River
El Dorado Springs	New York	Weminuche
Ellis	North Absaroka	White River
Fresno	Northern Cheyenne	Wichita Mountain
Frostburg Reservoir	Olympic	Wind Cave
Gates of the Mountains	Petersburg	Zion Canyon

Transmissometer

-- none --

Nephelometer

Bliss	Greer	Phoenix
Children's Park	Ike's Backbone	Tucson
Cloud Peak	Mammoth Cave	Vehicle Emissions
Dysart	Mount Rainier	Virgin Islands
Grand Canyon(Hance)	National Capital-Central	

Photographic

Bryce Canyon	Grand Canyon	Wichita Mountains

Operators of distinction

Monitoring sites are not all created equal. Some sites are easily accessed while others are remotely located and difficult to access. Snoqualmie Pass, Washington, fits into the latter category, but operator Mike Ames sees that it's done every Tuesday.

Mike has been the primary IMPROVE operator at Snoqualmie Pass for over two years, and served as backup operator several years before that. In his earlier years with the U.S. Forest Service, Mike was involved in timber management and silviculture, but he shifted to recreation about 10 years ago. His primary duties as forestry technician in the Okanogan-Wenatchee National Forest are to manage the recreation program, including visitor campgrounds. He also services the air quality monitoring instrumentation, which currently consists of the IMPROVE aerosol sampler. The USFS has also operated a nephelometer and camera system at Snoqualmie Pass in previous years.

"Winter access to the sampler is difficult," said Mike. "The site is at the summit of the ski area here; a 900' vertical gain and a half-mile to the DOT radio facility tower, where the aerosol modules are located." Even though winter access can be a challenge, Mike prefers to walk to the site and back. If several feet of new snow falls, he must hitch a ride with ski area personnel in their snowcat. If a ride is not available, he snowshoes, and if icy, he attaches crampons to his boots for the hike. And during holidays, when the ski area is open on Tuesday, he must ride the ski lift up and down, to the monitoring instrumentation and back.

Mike is an avid gardener and a classic car enthusiast. He lives nearby the forest with his wife, and two children who are in college. No matter what the challenges in accessing the monitoring site are, they're easier than funding two college educations. Even so, Mike sees that both are done as needed.

Mike Ames services the IMPROVE sampler every week -- no matter what the site conditions are in Snoqualmie Pass, Washington.

Feature article

BRAVO study reveals causes of haze at Big Bend National Park

(by M. Pitchford, NOAA; B. Schichtel, K. Gebhart, M. Barna, W. Malm, NPS; I. Tombach, consultant; and E. Knipping, EPRI)

Introduction

Big Bend National Park is located in a remote area of southwestern Texas, near the U.S.-Mexico border. In 1999, a comprehensive study began, sponsored by the U.S. Environmental Protection Agency (EPA), National Park Service (NPS), and the Texas Commission on Environmental Quality (TCEQ), to identify the source regions and types of pollutants responsible for increasing haze at Big Bend.

The Big Bend Regional Aerosol and Visibility Observational (BRAVO) Study was a multi-year assessment that included a 4-month intensive monitoring period from July through October 1999, followed by a 4-year data analysis and modeling effort. This article briefly summarizes the study processes, aerosol species found to cause visibility impairment in Big Bend, where the aerosols originate, and a conceptual model resulting from the comprehensive study.

The particulate sulfate attribution assessment conducted for the study, included the use of multiple attribution approaches to compare and reconciliate the results, and the use of long-term light extinction budget and trajectory residence time analyses to place the 4-month study period results into annual and multi-year prospectives. Additional information is available in the BRAVO Study Final Report, available on the IMPROVE Web site at *http://vista.cira.colostate.edu/improve/Studies/BRAVO/Studybravo.htm#FinalReport.*

Study design

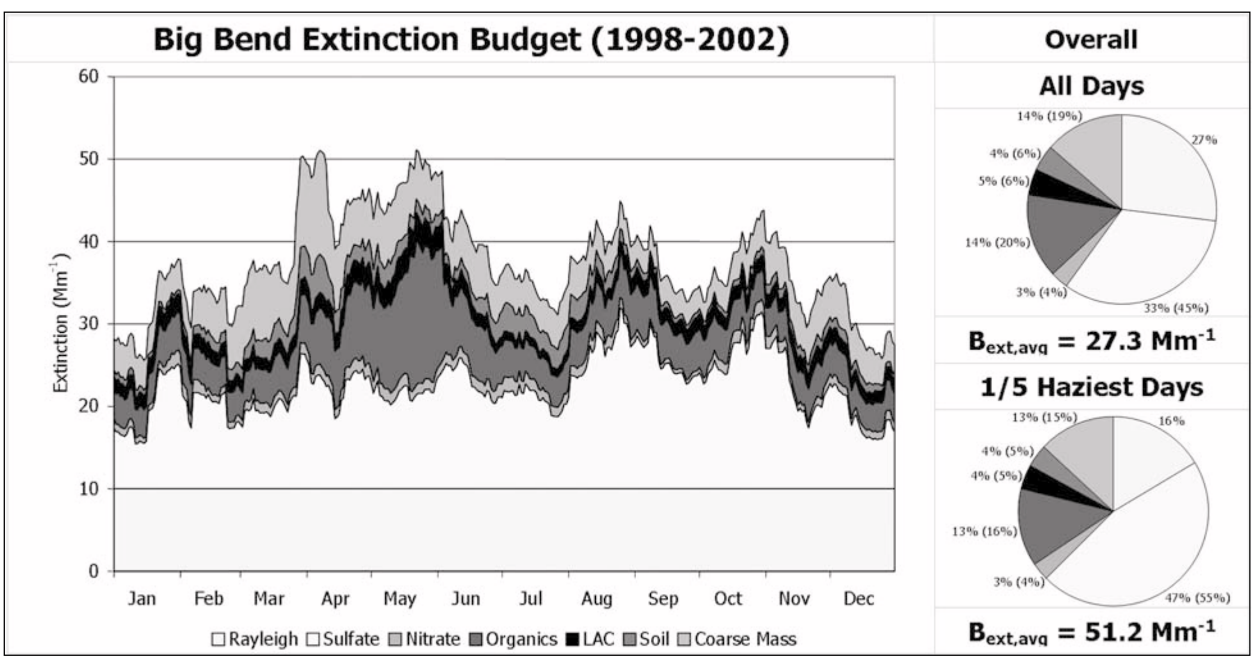
Analyses of historic data indicate that high haze levels are most frequent in two seasons: spring, and late summer to mid-fall. Figure 1 presents the 5-year composite (1998-2002) of the light extinction throughout the year, from IMPROVE aerosol measurements made every three days at Big Bend. This figure demonstrates seasonal variations of the total haze levels and of the composition of the particles responsible for haze. Spring and early summer is the period of greatest haze, while late summer and fall have episodes of high haze interspersed with relatively clear periods. Particulate sulfates, organic carbon, and coarse mass are responsible for most of the haze at Big Bend, while fine particles composed of light absorbing carbon (LAC), fine soils, and nitrates are relatively minor contributors.

BRAVO Study participants selected the summer/fall seasons for the field study to investigate the causes of Big Bend haze during a period when less was known about the contributions by emission sources in the U.S. and Mexico. Study participants also chose to investigate the sources of atmospheric sulfur, the greatest contributor to haze during this time of year.

The study used multiple data analyses methods and models to attribute haze to source regions. To better understand the nature of the pollutants responsible for haze and to support

Figure 1. Big Bend National Park five-year composite contributions to haze by components.

The pie charts show average percent contributions to light extinction. Percent contributions to particulate haze (non-Rayleigh light extinction) are shown in parentheses.



the information needs of the multiple attribution approaches, scientists designed an extensive field monitoring network that included 38 sites throughout and near Texas. All of these sites included $PM_{2.5}$, SO_2, and tracer sampling. Tracer sampling, especially at Big Bend and five other sites in west Texas, was designed to improve the understanding of transport and dispersion from tracer-release locations in Texas, and to evaluate the performance of source attribution methods. Four radar wind profilers were also deployed as part of the study to supplement upper air meteorological monitoring in the study region.

To help determine where pollutants originate that were affecting Big Bend's airshed, scientists compiled a comprehensive emissions inventory for air pollution sources within the study domain, including northern Mexico. Figure 2 is a map of the estimated magnitudes and locations of SO_2 emissions sources that were used in the study.

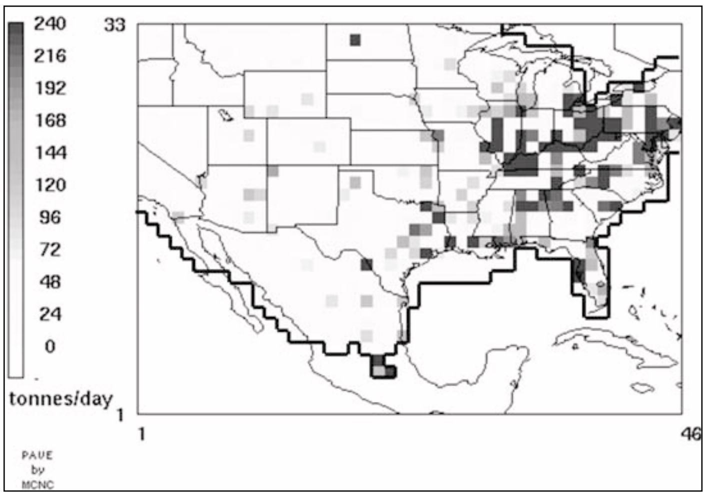


Figure 2. SO_2 emissions based on the 1999 BRAVO emissions inventory. No emissions were included beyond the black outline shown in the figure.

Study period attribution results

Atmospheric transport patterns to Big Bend vary throughout the year resulting in a seasonal cycle of different upwind source regions contributing to its haze levels. Study analyses show important sources and source regions for Big Bend haze. SO_2 emissions sources in Mexico, Texas, and in the eastern U.S. all contribute to Big Bend haze in varying amounts over different times of the year, with a higher Mexican contribution in the spring and early summer, and a higher U.S. contribution during late summer and fall.

Figure 3 (shown on the next page) shows the averaged particulate sulfate attribution results by source region for the refined approaches developed to reduce biases of the original attribution methods; all methods showed Mexico to be the largest contributor of particulate sulfate during the study period and the eastern U.S. being the second largest contributor. SO_2 source regions in the U.S. were shown to be significant contributors to the largest haze episodes in the late summer and fall, but otherwise to be infrequent sources of Big Bend haze. SO_2 sources in Mexico contribute much more frequently and over a longer period of time, but had smaller contributions during the largest haze periods compared to U.S. sources during the study period.

Haze conceptual model

Attribution results of the 4-month monitoring period were compared in a reconciliation process and placed in context using historic data to develop a conceptual model of the causes of haze at Big Bend. The source attribution results combined with aerosol and transport climatologies provide the basis for this conceptual model of Big Bend haze. Sulfate, carbonaceous, and crustal (i.e., coarse mass and fine soil) particles are responsible for most of the haze. Other aerosol components, including nitrates and sea salt, contributed little to the haze.

Coarse mass and fine soil contributions tend to be greatest between February and July most years. Airflow during the first few months of that period was from the west, including northwestern Mexico and southwestern U.S. regions that contain low ground cover playas and other areas that are subject to windblown dust events, and are the likely sources of some of the periods with high coarse mass and fine soil in the early spring. There is at least one Asian dust event over North America (April 26, 2001) that resulted in high coarse mass and fine soil concentrations. Other episodes with Asian dust are likely. During the summer, coarse mass and fine soil are frequently transported by winds from across the Atlantic Ocean and Gulf of Mexico from Africa. This is routinely seen by satellite remote sensing[1], by back trajectory analyses[2,3], and confirmed by the characteristic elemental composition of African dust compared with dust from the U.S.[4].

Carbonaceous (organic and LAC) particles contribute most to Big Bend haze during the spring and early summer. Smoke from large seasonal fires in Mexico and Central America has been documented[2] as the source of some of the largest of these episodes and may be responsible for much of the carbonaceous particulate matter contributions to haze during this time of year (e.g., May 1998). Secondary organic carbon particles (i.e., those formed in the atmosphere from gaseous organic compounds) also contribute to Big Bend haze, as was shown by carbon speciation during the BRAVO Study.

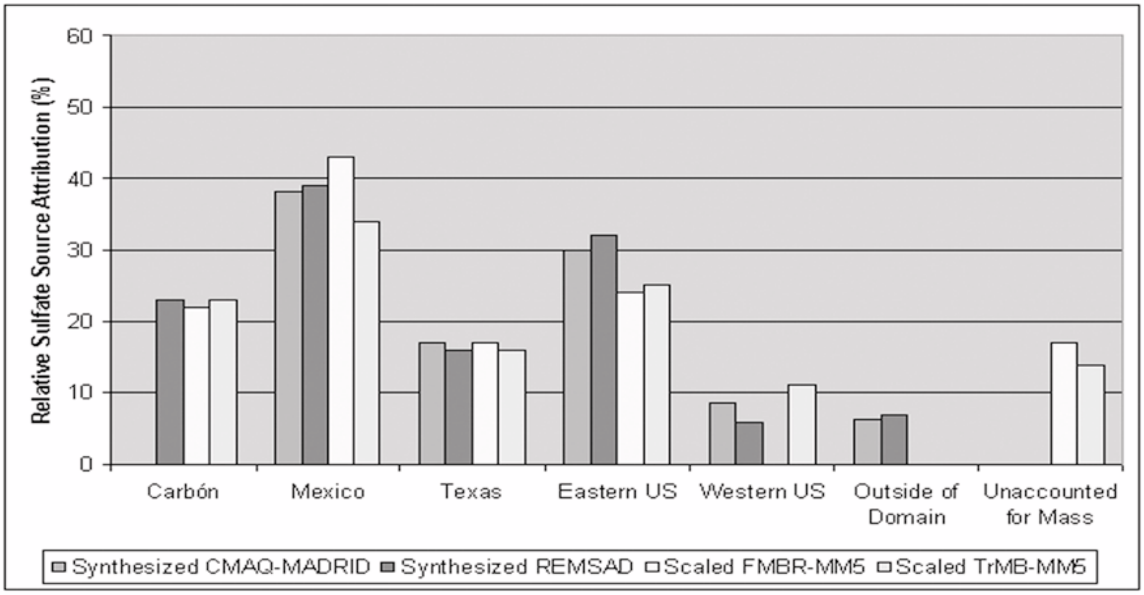
Sulfate compounds are often the largest contributor to particulate haze any time of year, but especially so in the late summer and fall. Particulate sulfate at Big Bend originates

Big Bend haze continued on page 6....

Big Bend haze *continued from page 5....*

Figure 3. Estimates of Big Bend's relative sulfate source attributions (in percent) by refined approaches. The relative contributions to the average estimated concentration at Big Bend during the entire BRAVO period.

The Unaccounted Mass is the difference between the scaled source attribution results and 100%.



from numerous SO_2 sources across various geographic regions. No single SO_2 source or source region is a dominant contributor to average particulate sulfate; however, some of the multi-day-long episodes of elevated particulate sulfate concentrations are predominantly from a single source region.

During the late summer and fall, the most intense haze episodes are associated with relatively infrequent airflow patterns that can transport a substantial fraction of the particulate sulfate at Big Bend from sources in the U.S. SO_2 emissions sources in Texas and in states east of Texas contribute more particulate sulfate during intense haze episodes than do the states west of Texas.

Frequent airflow from the southeast during the spring, summer, and fall results in contributions of particulate sulfate from SO_2 sources in northeastern Mexico that are much more frequent than those from the U.S. As a result of being frequently upwind, SO_2 sources in Mexico are thought to contribute more on average over a year to Big Bend particulate sulfate than do U.S. sources. As the largest SO_2 emission source in a frequently upwind region, Carbón power plants located in Mexico about 225 km east-southeast of Big Bend contribute more than any other single facility to average particulate sulfate concentrations at Big Bend.

Clearest visibility conditions at Big Bend occur most frequently in winter, when flow is most often from the north or west over areas of relatively low emissions density, and least frequently in the spring when airflows from the southeast can include smoke impacts from seasonal fires in Mexico and Central America. During summer and fall, airflow from the southeast that brings marine air from the Gulf of Mexico rapidly over northeastern Mexico is associated with the clearest visibility conditions during those seasons, while slower moving airflow over northern Mexico and from the eastern U.S. including Texas is responsible for the worst visibility conditions.

References

This article is summarized from:

Pitchford, M.L., Schichtel, B.A, Gebhart, K.A., Barna, M.G., Malm, W.C., Tombach, I.H., and Knipping, E.M., *Causes of Haze at Big Bend National Park - Results of the BRAVO Study and More*, Regional and Global Perspectives on Haze: Causes, Consequences and Controversies - Visibility Specialty Conference, Air & Waste Management Association, Asheville, NC October 25-29, 2004.

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4 Perry, D., Cahill, T., Eldred, R., Dutcher, D., and Gill, T., *Long-Range Transport of Saharan Dust into the Eastern United States.* J Geophys Res; 102:11 225_11 238, 1997.

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Visibility news *continued from page 2 ....*

Tropical storm cleans air at Great Smokies

In an extraordinary sequence, three tropical storms brought clean, pristine air to Great Smoky Mountains National Park, North Carolina/Tennessee, in September 2004. These events provide a dramatic demonstration of what the air quality should be for the region. Air quality monitoring and the Webcam at the Look Rock monitoring site captured the effect on air quality as Hurricanes Frances, Ivan, and Jeanne came ashore and proceeded up the Eastern U.S.

Looking at currently available data from the National Park Service's Gaseous Pollutant Monitoring Program, effects of the storms are clearly seen in Figure 1 below. Air quality monitoring stations at Great Smoky Mountains National Park recorded about 24 ppb ozone and about 2 µg/m³ $PM_{2.5}$ (24-hour averages) during the period when Frances was passing through in early September. The data were collected from continuous ozone and continuous TEOM particulate analyzers. Tropical storms carry clean ocean air with them and the high winds and rain tend to dilute and remove fresh air pollution.

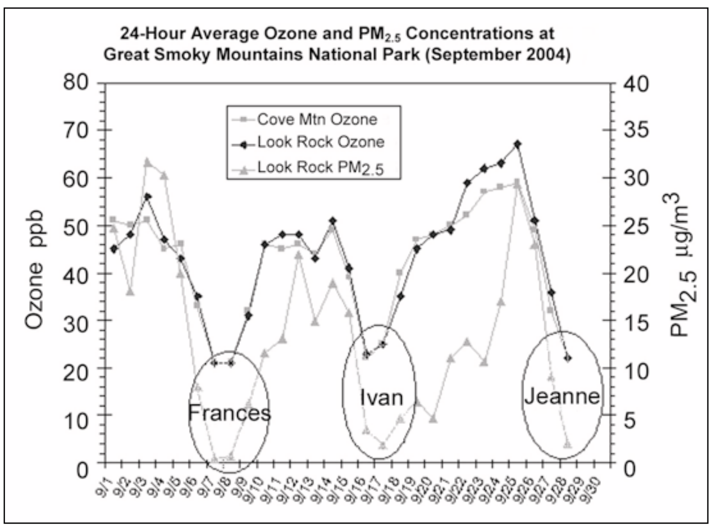

Figure 1. Clean air signatures are shown by the three tropical storm events that hit Great Smoky Mountains NP in September.

Hurricane Ivan was stronger, came ashore over the Gulf Islands, Florida/Mississippi, and proceeded to pass over the Great Smoky Mountains on September 16-17. Average ozone during the storm passage was about 25 ppb and $PM_{2.5}$ about 4 µg/m³. This storm dumped about 8 inches of rain in two distinct periods, before and after the eye passed. Three monitoring stations in the park (Look Rock, Cove Mountain, and Cades Cove), recorded nearly identical daytime ozone in the 18-34 ppb range during the passage (highest during the passage of the eye). The Cades Cove station normally experiences nightly low ozone values of about 5 ppb; however, its nighttime concentrations increased to 20-30 ppb for several days following the storm. Afterwards, it took 4 days for ozone to return to average values before the storm. $PM_{2.5}$ recovered even more slowly over the next week.

The Webcam at Look Rock (*http://www2.nature. nps.gov/air/WebCams/parks/grsmcam/grsmcam.htm*) captured the improvements in visual range as $PM_{2.5}$ was brought to very low values during the passage of Ivan (Figure 2). Visual range became increasingly worse as the $PM_{2.5}$ concentrations rose over the next week.

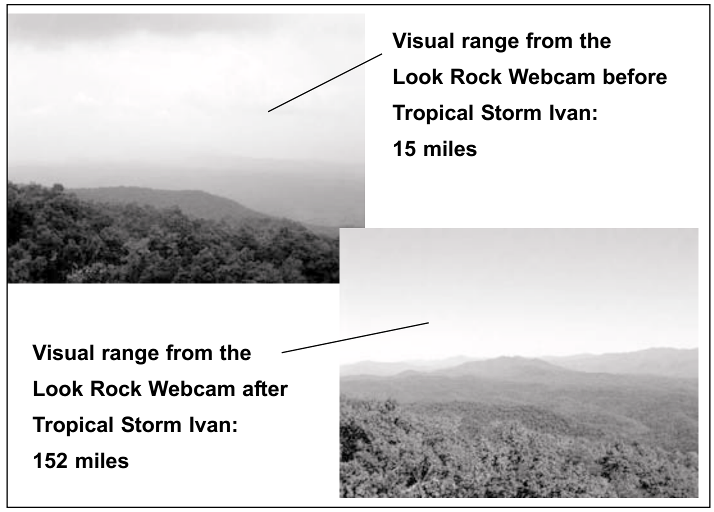

Figure 2. $PM_{2.5}$ decreased dramatically during Hurricane Ivan leaving beautifully clean air in the days following. Visual range increased from less than 20 miles to greater than 150 miles.

Rainfall from the storms was also quite high at Great Smoky Mountains, but the presence of cleaner air is evident in the acidity measurements from the National Atmospheric Deposition Program/National Trends Network. The pH of rain increased from an average of 4.4 before the storms, to 5.2 afterward -- an important acidity decrease. It will be interesting to see the concentrations of sulfate and nitrate in the storm rainwater once the lab results are back.

Ivan left clean signatures at Great Smoky Mountains; Mammoth Cave National Park, Kentucky; Big South Fork National River Recreation Area, Tennessee; and Shenandoah National Park, Virginia. In each case the cleanest air was in the 25-30 ppb ozone range, and several days passed before ozone increased to the concentrations prior to the storms. Detailed data of CO, NO_x, and SO_2 from continuous analyzers and filter data from CASTNet and IMPROVE at Great Smoky Mountains will provide an even more detailed record of these tropical storm events.

For more information contact John Ray at the National Park Service Air Resources Division. Telephone: 303/969-2820. Fax: 303/969-2822. E-mail: john_d_ray@nps.gov.

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IMPROVE Steering Committee members represent their respective agencies and meet periodically to establish and evaluate program goals and actions. IMPROVE-related questions within agencies should be directed to the agency's Steering Committee representative. Steering Committee representatives are:

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ASSOCIATE MEMBERS

Associate Membership in the IMPROVE Steering Committee is designed to foster additional IMPROVE-comparable visibility monitoring that will aid in understanding Class I area visibility, without upsetting the balance of organizational interests obtained by the steering committee participants. Associate Member representatives are:

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Government organizations interested in becoming Associate Members may contact any Steering Committee member for information.

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The IMPROVE Program was designed in response to the visibility provisions of the Clean Air Act of 1977, which affords visibility protection to 156 federal Class I areas. The program objectives are to provide data needed to: assess the impacts of new emission sources, identify existing human-made visibility impairments, and assess progress toward the national visibility goals as established by Congress.

To submit an article, to receive the IMPROVE Newsletter, or for address corrections, contact:

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