National Wildfire Coordinating Group (NWCG) Smoke Committee (SmoC)

Advisory on Linking Air Quality Index, Visible Range, and PM2.5 Concentrations

- DRAFT Discussion Paper on Issues, Caveats, and Research Needs -

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Summary/Issue: States in the humid southeastern US (ex. Louisiana, South Carolina) are investigating or already implementing a methodology developed in the arid intermountain west where particulate matter with aerodynamic diameter less than or equal to 2.5 micrometers (PM2.5) concentrations are estimated from a visual range measurement. The PM2.5 concentration is then linked with the air quality index (AQI) in order to inform the public about potential health impacts in wildfire situations where no monitoring data are available. The purpose of this paper is to generate discussion on this topic based on the concerns outlined below.

Concern 1: The linkage between visual range, PM2.5 concentration and AQI was created based upon a single empirical study performed in Helena, Montana in 2000 and an important caveat that is often ignored is that **the linking of AQI with visible range and PM2.5 concentrations is only applicable in arid environments and should never be used when relative humidity is greater than 65%. The AQI is used nationally by EPA, and State Air Quality Agencies and Health Departments to inform the public about current and forecasted air quality conditions** and this methodology is being used in predominantly western wildfire situations to warn the public about potential health impacts. It is critical that existing data (the Montana study) be applied correctly and where data do not exist, that studies be performed, or else **misinformation about wildfire smoke impacts are being relayed to the public**.

Concern 2: Another concern is the fundamental use of visual range to estimate PM2.5 concentrations. Communication with experts in visibility from the IMPROVE project indicate that using visual range to estimate PM2.5 concentration has a factor of uncertainty of 3-5 times associated with it. Thus, if you estimate a concentration of 20 $\mu g/m^3$ from a visual range measurement, that concentration could actually be as low as 4 $\mu g/m^3$ or as high as 100 $\mu g/m^3$. Applying such a number with that degree of uncertainty to a narrow range of PM2.5 concentrations used in the AQI (e.g. 0-22=Good, 22-40=moderate, 40-65=Sensitive Groups, 65-150=Unhealthy etc.) implies a level of specificity not applicable to the method and can again result in mis-information to the public. In this example, is air quality "Good" (4 $\mu g/m^3$)? Or, is air quality Unhealthy (100 $\mu g/m^3$)? What should be told to the public?

Concern 3: The AQI is a 24-hr average based value, thus a constant visual range would need to be maintained for a 24-hr period in order to be correlated with a 24-hr average PM2.5 concentration. This can be quite difficult to achieve especially under conditions of smoke impacts which can vary dramatically with diurnal meteorological patterns.

Concern 4: The Montana study is based upon a wildland fire smoke-only impact to visible range and PM2.5 concentrations. In many areas of the nation (ex. California, southeastern US), anthropogenic sources (e.g. industrial sources, mobile sources, power plants) can mix with the smoke, impacting the visible range and PM2.5 concentrations in ways that are not accounted for in the Montana data.

Bottom line: The wide-spread application of this method has arisen out of the need for PM2.5 information in wildfire situations where monitoring data are not available. Monitoring data are critical in order to communicate with the public when there are significant wildfire impacts. SmoC is concerned about this and wants to generate discussion on this topic.

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Possible Research Need(s): A literature review and dialog about linking visible range with PM2.5 concentrations needs to occur with experts in the field of smoke measurements and visibility. There is a rich history and dataset of measurements associated with the Interagency Monitoring of PROtected Visual Environments (IMPROVE) project that can be tapped as well as other smoke measurement studies. Depending upon the outcome of the literature review and dialog, an identification of additional measurement campaigns and research can occur. Datasets need to include field measurements conducted under a range of dry to very humid (including superfog) environments, over time periods from 1-hr to 24-hrs, in areas where wildland fire smoke is contributing to the visible range degradation and PM2.5 concentrations. These areas can also have other sources adding to the situation. Ideally, datasets should include measurements of trace gas and speciated aerosol concentrations, light extinction and scattering, visual range (for the duration of the measurements), micrometeorological data and taking representative pictures under measurement conditions if applicable. Based upon the analysis of existing data and potentially new data, the following key questions need answering:

- Is linking visible range with PM2.5 concentrations viable?
- Are there some areas of the country or particular conditions where this linkage can be used and others where it should not be applied?
- Given that PM2.5 concentrations can be extrapolated to AQI levels and then public health impacts, is there utility in this approach for public warnings?

JFSP Smoke Science Plan Relationships: This research need aligns with two JFSP Smoke Science Plan Objectives: Fire and Smoke Model Validation and Smoke and Populations.

- Smoke and Populations: *"We need to improve our understanding of how people value their personal health and the health of their surrounding ecosystems, especially in circumstances where fire, climate change and increasing populations are interconnecting."* We need to ensure that correct information about smoke health impacts from wildland fire are being relayed to the public.
- Fire and Smoke Model Validation: The work being described in this paper can be directly applied to smoke model validation and identifying areas that need development within those modeling systems.

JFSP Smoke expert consultants have agreed to shepherd and scope developing this research need based on these tenants of the Smoke Science Plan.

Background: The NWS office in Charleston, South Carolina is investigating using the product shown in Figure 1 this upcoming wildfire season. This product links visual range with AQI and the messages that can then be shared with the public.

Proposed Product Guideline:

Visibility	Product Issued	AQI Health Indicator for Particle Pollution
≥10	No Product	Good: There are no air quality issues from particle pollution.
6-9	No Product	Moderate: Unusually sensitive people should consider reducing prolonged or heavy exertion.
3-5	Special Weather Statement	Unhealthy for Sensitive Groups: People with heart or lung disease, older adults and children should reduce prolonged or heavy exertion.
1-3	Dense Smoke Advisory	Unhealthy for All Groups: People with heart or lung disease, older adults and children should avoid prolonged or heavy exertion. Everyone else should reduce prolonged or heavy exertion.
≤1	Dense Smoke Advisory	Very Unhealthy for All Groups: People with heart or long disease, older adults and children should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion.

Figure 1. Proposed South Carolina visual range and air quality index linkage.

Furthermore, *Wildfire Smoke, A Guide for Public Health Officials,* was recently used in Louisiana, an area not typically considered to be dry or arid. http://www.jeffparish.net/downloads/3753/7690-MarshFireImpactOnJeffParish.pdf. The *Wildfire Smoke, A Guide for Public Health Officials* includes a table comparing air quality categories with $PM_{2.5}$ concentrations, visible range, and recommended actions, but states that the visible range values are for arid conditions. http://www.epa.gov/ttnamti1/files/ambient/smoke/wildgd.pdf. The document was updated in July 2008 and includes the following caveats:

> "***Furthermore, the above visible range categories for PM levels only apply in dry air conditions. For a given PM level, visible range decreases substantially at relative humidity above 65%, therefore, this method of estimation should not be used under conditions of high humidity.*** Work is being done to incorporate humidity as a factor in the visible range index, and will be included in this guide when it is available. For now, in humid conditions, individuals may have to rely on common sense in assessing smoke conditions (e.g., mild, moderate, heavy smoke) and the kinds of protective actions that might be necessary."

Several western States are using visible range versus AQI charts, which appear to stem from a single empirical study performed in Helena, Montana in 2000 by John Coefield, a meteorologist for Montana Department of Environmental Quality (now retired) and Cyra Cain. We are concerned that this product is finding its way into an increasing number of publications without the users understanding the limitations, especially in humid areas of the country. Some examples of this in use are available at the following links and in Table 1:
Alaska: http://co.fairbanks.ak.us/AirQuality/Docs/ParticulateLevels.pdf
Arizona: http://www.azdhs.gov/phs/oeh/pdf/smoketable.pdf
Montana: http://www.deq.mt.gov/FireUpdates/BreakpointsRevised.mcpx
New Mexico: http://www.navajonationepa.org/airq/wildfire11.html
California:
http://www.co.shasta.ca.us/ShastaCountyInternet/Resource_Management/docs/Visually_Estimating_PM_Levels.sflb.ashx
Colorado: http://www.colorado.gov/airquality/wildfire.aspx

Table 1. Colorado linkage of air quality index (AQI) with 24-hr PM2.5 concentrations, 1-hr PM2.5 concentrations, and visual range (miles).

Air Quality Category (AQI)	**24-Hr PM2.5 ($\mu g/m^3$)[1]**	**1-Hr PM2.5 ($\mu g/m^3$)[2]**	**Visual Range (miles)[3]**
Good	0.0 - 22.0	0.0 - 40.0	10 or more miles
Moderate	15.5 - 40.4	40.1 - 80.0	5-10 miles
Sensitive Groups	40.5 - 65.4	80.1 - 175.0	3-5 miles
Unhealthy	65.5 - 150.4	175.0 - 300.0	1.5 - 3 miles
Very Unhealthy	150.5 - 250.4	300.1 - 500.0	1. - 1.5 miles
Hazardous	≥250.5	≥500.1	≤1 mile

Atmospheric Chemistry: Water vapor, secondary aerosol formation, anthropogenic source interactions: As fuel is heated and combusted, water vapor is released into the atmosphere. This water can condense onto fine particulate matter from a fire and from other sources of pollution, reducing visibility and can play a role in the in-plume chemistry of secondary organic aerosol production. Where ambient atmospheric humidity can be high, a common situation in the Southeast US but possible across the country, the addition of water vapor from fire to the atmosphere, combined with existing water vapor and nighttime cooling and inversions, can cause the atmosphere to become saturated (or nearly saturated). As temperatures decrease in the evening and especially early morning hours, the water vapor will condense out of the atmosphere onto the fine particulate matter released from the fire. This can quickly create a thick white-out fog ("superfog") that pools in low-lying areas reducing visual range to zero. This phenomenon has been attributed to numerous traffic accidents and fatalities, such as the 1/29/2012 accident outside Gainesville, Florida. In-situ measurements of meteorological, aerosol, and trace gases, before and during superfog events are needed.

Primary and secondary aerosols from anthropogenic sources can also be present to further reduce visible range and increase PM concentrations in potentially non-linear ways. Anthropogenic sources can be a source of sulfates (power plants) and nitrates (engine combustion) which can react with ammonia to create various forms of ammonium-sulfates and ammonium-nitrates. These reactions are highly hydrophilic and thus aerosol water content is an important component to total aerosol composition.

Smoke Photo Series: Initial work related to this has begun with the Forest Service Smoke Photo Series Guide. This guide is developed by the University of Idaho College of Natural Resources with collaboration from the USDA Forest Service, NWCG Smoke Committee, and monitoring data collected from the National Park Service. The primary purpose of the guide is to serve as a tool for the estimation of air quality using visual range. Both particulate matter and ozone have been shown to impact visibility and the decline in visibility present in the photo Turtleback Dome photo (Figure 2) is assumed to be due to the presence of these pollutants emitted from wildland fire though other pollutants could be present. Other factors such as humidity may also impact visibility and thus micrometeorological parameters are provided.

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Ozone (ppm, 1 hour)	0.078	Relative Humidity (%)	22
PM2.5 (μg/m^3, 1 hour)	47.0	Solar Radiation	796
PM10 (μg/m^3, 1 hour)	9.9	Temperature (C)	25.2
		Solar Declination	21.98

Figure2: Turtleback Dome, Yosemite National Park, California – Smokey Conditions (7/11/2008 1000 PST)

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WINHAZE: Another related tool that may be useful to investigate effects of RH% and aerosol hygroscopicity on visual range and PM2.5 concentrations is the WINHAZE program developed as part of the Interagency Monitoring of PROtected Visual Environments (IMPROVE) project. In WINHAZE a user can enter speciated PM2.5 information that is used to calculate light extinction and visual range. The program is based upon the decades of monitoring and measurements made at National Parks, Wilderness Areas, Forests and other scenic areas across the US. For a given set of parameters, WINHAZE will make a photo of the location more or less hazy. An example is provided in Figures 3a and 3b of the Great Smokey Mountains National Park, where in both figures PM2.5 concentrations are approximately 16.5 $\mu g/m^3$. The differences between 3a and 3b are due to relative humidity and aerosol hygroscopicity, where Figure 3a is Great Smokey Mountains National Park under low relative humidity and low aerosol hygroscopicity (visual range of 78 miles) and Figure 3b is the Park under high humidity and high aerosol hygroscopicity (visual range of 28 miles) – illustrating how humidity, and aerosol interaction with humidity, can have a large impact on visual range.

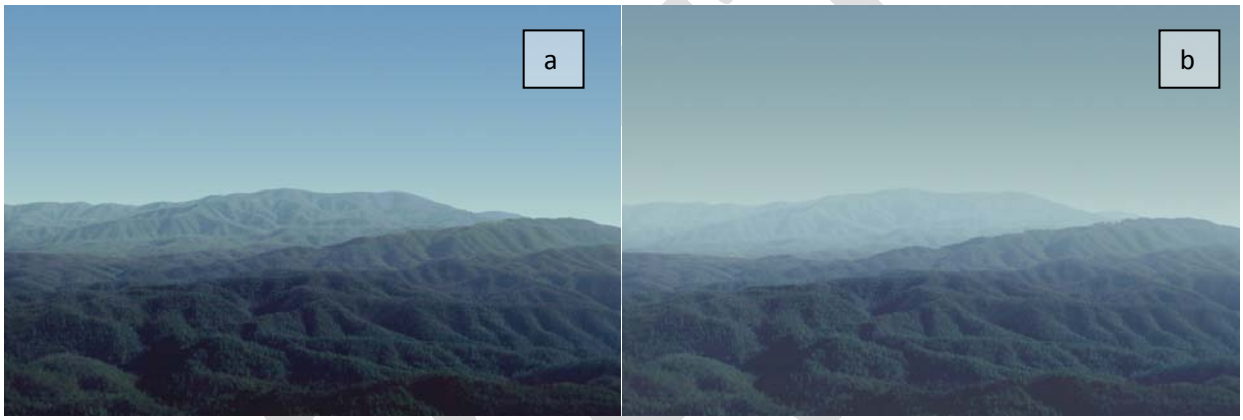

Figure 3. Great Smoky Mountains National Park a) with a visual range of 78 miles (low humidity, low aerosol hygroscopicity) and b) with a visual range of 28 miles (high humidity, high aerosol hygroscopicity. Total aerosol concentration is approximately 16.5 $\mu g/m^3$ in both pictures.

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