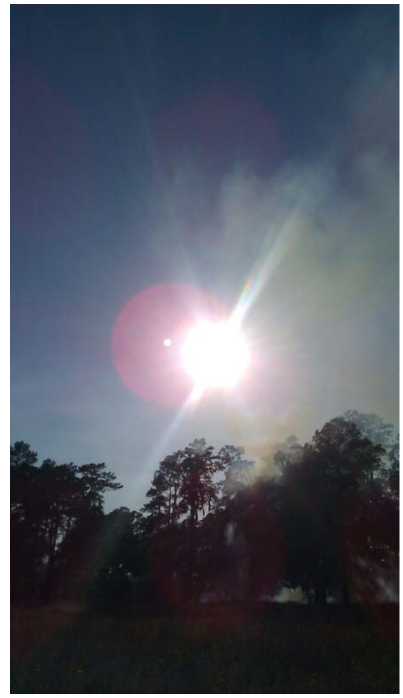


Fire is an essential ecological disturbance, providing many benefits to the environment in terms of wildlife, water and soil quality, and nutrient cycling. Prescribed burning can also be a means of protecting air quality by mitigating the occurrence of large wildfires and reducing invasive species. However, fire produces smoke which contains particulate matter (PM), ozone precursors, greenhouse gases, and other trace gases. Basic Smoke Management Practices (BSMPs) applied on prescribed burns can mitigate the impacts of smoke to public health, public safety and nuisance, and visibility.

Smoke is not like other air pollution sources--a direct control cannot be put on it such as can be applied to a power plant smoke stack--rather a variety of environmental factors must be taken into account to manage both the burn and the smoke from the burn. BSMPs outlined here offer a suite of options that a fire manager can utilize to reduce the impacts of their smoke. The Smoke Management Guide for Prescribed and Wildland Fire, 2001 edition (http://www.treesearch.fs.fed.us/pubs/5388) and the national smoke management website (http://www.nifc.gov/smoke) offer further technical information on how to manage smoke.

The six BSMPs discussed in this Technical Note (and summarized in Table 1) have applicability depending on the type of burn, fuels to be burned and level of effort needed to address air quality concerns. Not all BSMPs are applicable to all situations, therefore fire managers are urged to investigate the information available and applicable to their area and needs. Furthermore, these six BSMPs are only a subset of possible BSMPs and others can be adopted as needed such as no burning after November 15 due to inversions. BSMP's are utilized by the individual fire manager and may be an expectation of a state-wide smoke management program or employed to maintain the social acceptability of using prescribed fire and managing air quality impacts of smoke.

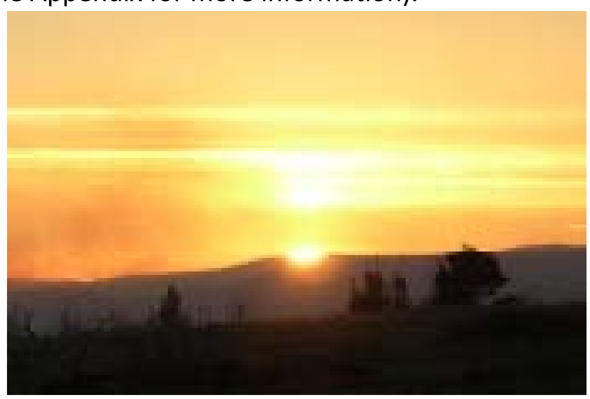
Table 1. Summary of Basic Smoke Management Practices (BSMPs), benefit achieved with the BSMP, and when it is applied (before, during or after the burn).

Basic Smoke Management Practice	**Benefit achieved with the BSMP**	**When the BSMP is Applied – Before/During/After the Burn**
Evaluate Smoke Dispersion Conditions	Minimize smoke impacts	Before, During, After
Monitor Effects on Air Quality	Be aware of where the smoke is going and degree it impacts air quality	Before, During, After
Record-Keeping/Maintain a Burn/Smoke Journal	Retain information about the weather, burn and smoke. If air quality problems occur, documentation helps analyze and address air regulatory issues	Before, During, After
Communication – Public Notification	Notify neighbors and those potentially impacted by smoke, especially sensitive receptors	Before, During
Consider Emission Reduction Techniques	Reducing emissions can reduce downwind impacts	Before, During

Share the Airshed – Coordination of Area Burning	Coordinate multiple burns in the area to manage exposure of the public to smoke	Before, During, After

BSMP #1: Evaluate smoke dispersion conditions to minimize smoke impacts
There are many ways to evaluate smoke dispersion conditions such as identifying smoke sensitive receptors, smoke modeling to determine where smoke may go and degree of impact, and most importantly use of readily available meteorological forecasting of conditions that influence smoke dispersion. Based on all this information, adjustments can be made as necessary to ignition date/time, firing sequence, and post-burn mop-up procedures, etc. The Appendix gives information about the type of meteorological information that may be available in your area and atmospheric parameters that influence smoke dispersion, such as: wind speed (near the surface and aloft), wind direction, mixing height, ventilation index, atmospheric stability, vertical temperature profile of the atmosphere and inversions, and water vapor (both in the atmosphere or released from the fire).

Prior to burning it is important to identify smoke sensitive areas downwind of burn areas such as highways, communities, airports, scenic vistas, Class 1 visibility protection areas, air quality nonattainment areas (see page 8), etc. Fire managers should then determine meteorological conditions including wind speed, direction and mixing height that will promote smoke dispersal away from sensitive areas and prevent ground level smoke accumulations. Burning should be avoided when mixing heights are low or a temperature inversion exists (see the Appendix for more information).

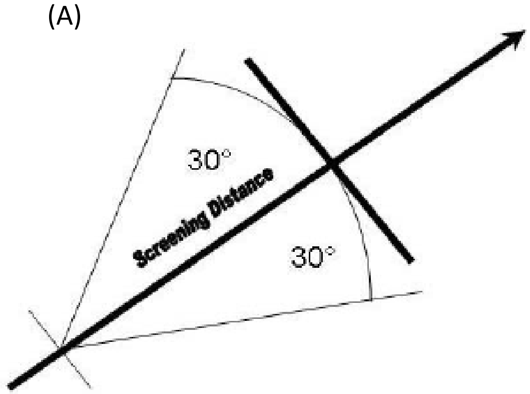


During burn operations

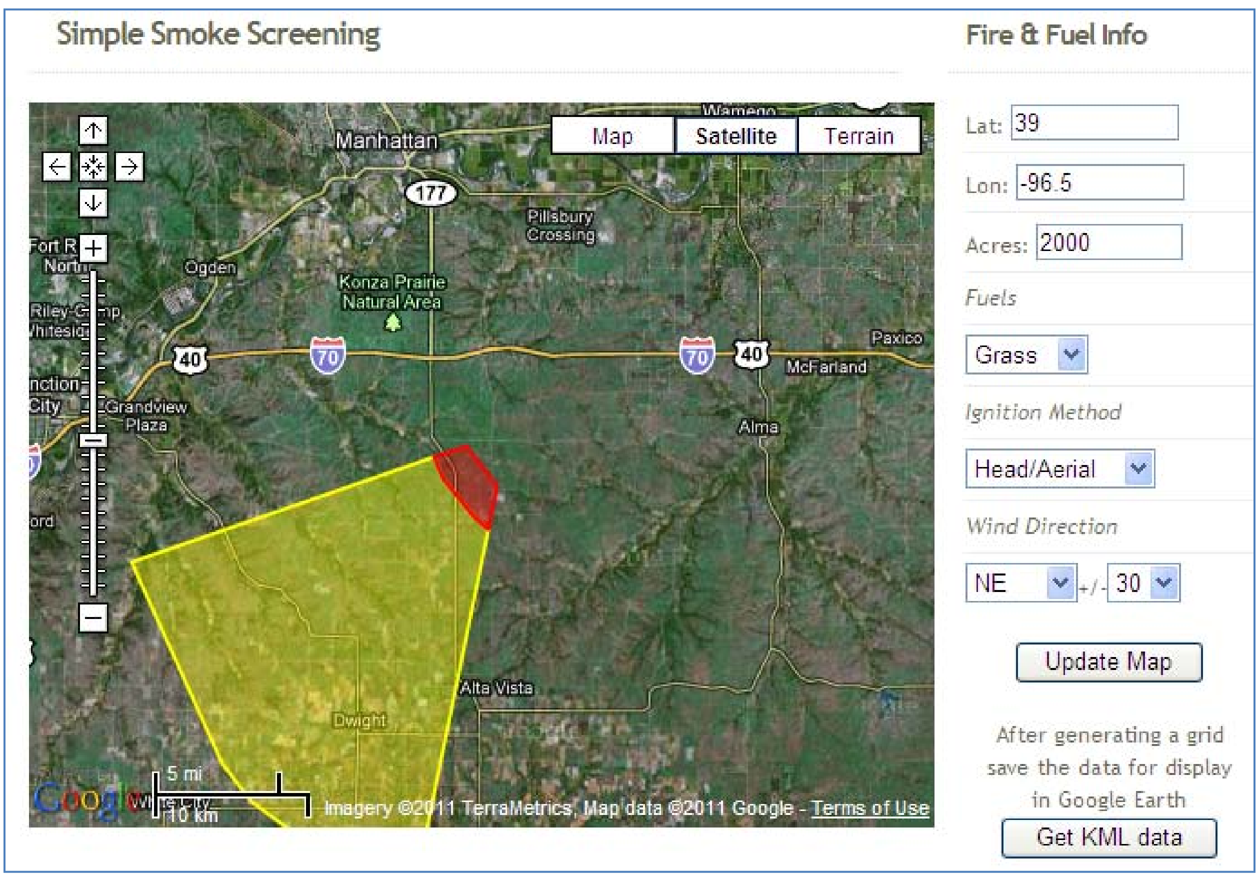
- **(Critical)** Fire managers should obtain and use the most up-to-date meteorological forecast (National Weather Service (NWS, http://radar.srh.noaa.gov/fire/) Spot Fire Weather Forecast or other data source), to inform whether to ignite a burn or not and to time ignitions to maximize dispersion away from sensitive areas.
- Where possible, obtain and use air quality forecasts such as AirNOW (http://www.airnow.gov) for your area and downwind to help time ignition to avoid periods when air quality is expected to be exceeding, or close to exceeding, the National Ambient Air Quality Standards (NAAQS). Nearby air quality monitoring sites may also be assessed to verify current air quality conditions.
- Verify the forecasted weather conditions whenever possible with local observations such as from Remote Automated Weather Stations (RAWS), and on-site or nearby weather monitoring sites. Small test burns or use of pilot balloons (which give wind speed and wind direction information vertically in the atmosphere) are also a means of getting an idea of both potential fire behavior and smoke dispersion.

After burn operations smoke can continue to be generated from smoldering fuels such as piles, large down trees/stumps, and in some areas of the country the organic duff layer. Meteorological and topographical features can keep the smoke near the surface and transport it along drainages, especially during the nighttime hours (see the Appendix). This should be assessed for potential impacts to smoke sensitive receptors and especially roads and post burn mop-up procedures may be needed to extinguish smoldering fuels.

(A)



Simple Smoke Screening Tool – Recommended (*http://shrmc.ggy.uga.edu/maps/screen.html*)
The online simple smoke screening tool is a simple, easy-to-use application that relies on google maps and the methodology laid out in the Southern Forestry Smoke Management Guide (http://www.srs.fs.usda.gov/pubs/viewpub.php?index=683, Figure (A)) to highlight the critical smoke impact area (shown in red, Figure (B)) and the smoke impact area of concern (shown in yellow, Figure (B)) downwind from a fire. This tool was developed and is hosted online by the Forest Service Southern Research Station. By entering information about fire location, acres to burn, fuel type (grass, shrubs, litter, slash), ignition method (backing fire, heading fire), and wind direction, the application will identify the potential downwind smoke impact area. Zoom and pan capabilities, used to identify smoke sensitive receptors such as towns, highways, schools, etc., are provided with this google map application. Actual ground level impact will vary based on mixing height and other meteorological conditions and topographical elements influencing the burn (see the Appendix), but the tool provides an excellent first step in understanding potential levels of smoke impacts from a proposed burn. **Use of this tool is highly recommended.**

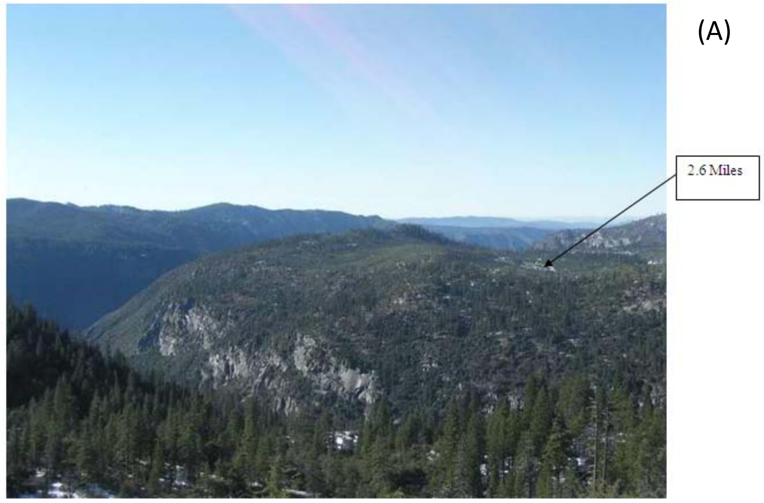


BSMP #2: Monitor the effects of the fire on air quality

Monitoring the effects of fire on air quality can include keeping track of where the smoke goes, how high it goes and whether it disperses well or is tight and dense, which can be done through visual monitoring and can be documented by notes, photographs, aircraft observations, satellite imagery, air quality monitoring data, and post-burn evaluations. The air quality in the vicinity of sensitive receptors such as towns, highways, schools, etc. is of particular importance to monitor.

Before igniting, assessing the air quality conditions is a good way to avoid making a condition worse. Utilize the AIRNOW forecast for your area and assess current air quality conditions by checking local and downwind air quality monitors when available.

Turtleback Dome, Yosemite National Park, California – Clear



(A)

Turtleback Dome, Yosemite National Park, California – Smokey

(B)

To give an idea of how smoky conditions can correlate with visible range, Figures A and B are shown here. They are examples from a smoke photo series under development by the US Forest Service in cooperation with the National Park Service (NPS). Figure A shows a non-smoky atmosphere and how visible a point 2.6 miles away is, while Figure B shows the same view but under smoky conditions and the affect on visible range. The reduction in visible range typically indicates the degree of impact of pollution. When evaluating smoke effects on visible range it is important to take into account relative humidity and the presence of urban/anthropogenic pollution – a given visual range for northern California (as shown here) could be very different in the southeastern US which has much higher humidity (See the Appendix Water Vapor Section). In situations with smoke and high relative humidity white-out conditions can occur which can be of particular concern for roadways. For judging the severity of air quality impacts, the air quality index provides a scale from “good” for clean air to “hazardous” for extremely polluted situations. See http://airnow.gov/index.cfm?action=aqibasics.aqi for more information.

BSMP #3: Record-keeping of BSMP's, fire activity, and smoke behavior

Record-keeping can be as simple as keeping a personal burn/smoke journal. Having a record of the weather, BSMPs applied on the burn, the fire activity (fuels, area burned, ignition time, etc.) and smoke behavior can be used to help assess the conditions and burns that meet goals, and provide lessons learned if goals were not met to expectation or if there were smoke problems identified at downwind receptors (for example, did smoke cause hazardous conditions across a road?). In cases where air quality monitoring data exceed national and/or local standards, and if the state decides to seek to remove the data from the monitoring record, then documentation of BSMPs are critical. In these cases the state may not seek such documentation until several years after the event. Record-keeping should document the BSMPs used and include: notes on weather forecast and conditions both during and after the burn which influenced the dispersion of smoke, acres treated, location, date, and time of the burn, how much and what was burned (fuels information), and noting smoke impacts if any. This documentation should be retained by the fire manager long enough to meet regulatory time frames.

BSMP #4: Communication – Public Notification

Fire managers need to notify appropriate authorities and those potentially affected by the smoke including the public at sensitive receptors. In addition, it is useful to prepare for contingency actions during the fire to reduce exposure of people at such receptors if an unintended impact were to occur.

Routine procedures should be established to notify the public of the burn (especially sensitive populations and appropriate authorities such as air regulators, public health officials and local fire department). As a contingency measure during the burn, notification of these same parties and appropriate air quality and/or county health authority should occur if there is an unintended smoke impact. Fire mangers should consider fire management and suppression options such as mop-up or cutting off a burn to minimize such an impact.

BSMP #5: Consider use of emission reduction techniques (ERTs)

There are several methods for reducing emissions that can be considered when planning and conducting a burn. Care should be taken to ensure the methods chosen actually reduce the amount of total emissions over time, not just delay them. Some ERTs can also reduce plume rise and could increase surface smoke concentrations. It is recommended that documentation be kept on the use of ERTs and where possible a quantification of emissions averted for air quality regulatory purposes. Key ERTs include reducing the fuel load and burning the minimum material to meet objectives, reducing fuel burned (for example, burn only the area needed and prevent the fire from spreading, extinguish the smoldering burns, burn prior to precipitation, or burn before litter falls), and increasing burning efficiency (for example, allow the material to dry before burning, minimize soil content in slash piles, burn in piles, or use a backing fire when grass is burned).

Identify and document appropriate NRCS conservation practices that can help reduce emissions, such as: Brush Management, Clearing and Snagging, Firebreak, Forest Stand Improvement, Fuel Break, Prescribed Grazing, and Woody Residue Treatment.

For more information on emission reduction techniques see The Smoke Management Guide for Prescribed and Wildland Fire, 2001 edition (http://www.treesearch.fs.fed.us/pubs/5388) and the Western Regional Air Partnership Fire Emissions Joint Forum document on ERTs at: http://www.wrapair.org/forums/fejf/documents/ert/index.html

BSMP #6: Share the airshed/air basin to minimize exposure of the public – Coordination of Area Burning

Develop a communications and information-sharing network among fire managers who may be in the burn vicinity on the same day or who could cumulatively impact an area or sensitive receptor. This enables coordination and planning of ignitions to cooperatively limit burning so as not to overwhelm the ability of the atmosphere to disperse the smoke from burns and minimize exposure of the public. This also helps prevent contributing to cumulative or adverse downwind impacts from smoke. Determining air quality conditions before ignition takes place should be a consideration for coordination. Air quality information can be obtained from the EPA AIRNOW website (http://www.airnow.gov) or from local/state air quality monitoring networks or agencies. The National Oceanic Atmospheric Administration (NOAA) Hazard Mapping System (HMS) analyzes satellite fire detections from multiple satellites to present a view of current fire hot-spots and satellite-visible smoke plumes across North America (http://www.osdpd.noaa.gov/ml/land/hms.html). This can give information about other burning occurring across the region.

RELATED TOPICS AND TRAINING

Air Quality and Atmospheric Change in NRCS

NRCS has four Air Quality and Atmospheric Change (AQAC) resource concerns: Odor, Particulate Matter, Ozone Precursors and Greenhouse Gasses. **Four online courses have been developed that are available through AgLearn, they are: Air Quality, Climate Change and Energy; Why Should we Care About Air Quality?; Air Quality Resource Concerns; and Greenhouse Gasses and Carbon Sequestration.** To learn more about AQAC issues within the agency and to access the online courses, visit the AQAC website at http://www.airquality.nrcs.usda.gov.

Smoke and the Clean Air Act

BSMPs can protect the public from smoke exposure, help avoid an exceedance of a National Ambient Air Quality Standard (NAAQS) and minimize impacts on sensitive areas such as Class 1 visibility areas. There are six criteria pollutants regulated under the clean air act; particulate matter, ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide and lead. With regards to fire, particulate matter and ozone are of concern, and near the fire carbon monoxide can be a concern as well. When concentrations of a criteria pollutant are measured above the level of the standard for the particular pollutant, then an area can be determined to be in nonattainment of the standard and subject to controls as delineated in a State Implementation Plan (SIP). The Exceptional Event Rule (e.g. "EPA 40 CFR Parts 50 and 51 Treatment of Data Influenced by Exceptional Events") affords the states protection from being put into nonattainment for events that are not controllable. Such events can be natural (ex. wildfires) or due to other reasons including prescribed fires. Documented use of BSMPs can allow for a state to flag data and seek exclusion for an exceedance of the NAAQS if appropriate Exceptional Event Rule (EER) criteria are met. BSMPs can also be considered as smoke management techniques as cited in the Regional Haze Rule (RHR) and therefore used to address pollution that causes visibility impairment in Class I areas; approximately 156 national parks and wilderness areas across the US. **Fire managers can learn more about this by taking the approximately one hour online course "Smoke Management and Air Quality for Land Managers" available at**: http://www.cnr.uidaho.edu/smoc/.

National Coordination on Smoke Issues

The National Wildfire Coordinating Group (NWCG) Smoke Committee (SmoC) has been established to provide interagency leadership, coordination and integration of air resource and fire management objectives to support overall land management goals. Members are from the Bureau of Land Management, Fish & Wildlife Service, National Park Service, Bureau of Indian Affairs, USDA Forest Service, and the National Association of State Foresters (eastern and western representatives), as well as the Natural Resources Conservation Service, the National Association of Clean Air Agencies (NACAA), The Nature Conservancy (TNC), and Department of Defense (DoD). SmoC has three Subcommittees; The Smoke Managers Subcommittee which works to provide relevant technical, administrative, and organizational information and feedback for operational smoke managers, forecasters and modelers; The Technical Smoke Topics Subcommittee which addresses technical smoke issues; and The Training subcommittee which works to advance training in smoke and air quality topics for the wildland fire community. More information is available on the public MyFireCommunity "Air Quality and Fire Issues" neighborhood at:
http://www.myfirecommunity.net/Neighborhood.aspx?ID=279

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Attribution: The information provided in this document is based on discussions between Forest Service, NRCS, and Department of Interior prescribed fire practitioners, smoke management specialists, and air quality program personnel.

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APPENDIX – Meteorological Parameters for Smoke Dispersion

This appendix discusses meteorological parameters applicable to smoke dispersion. Many of these parameters may be available from local forecasts. Check with your local National Weather Service office, air quality regulatory department, or other public land management agencies in the area.

Wind Speed and Direction

Wind speed and direction can play an important role in the dispersion of smoke and the location of potential smoke impacts. ***Wind speed will help disperse a plume; however, strong surface wind speeds will also cause a plume to lay-down near the surface and inhibit vertical dispersion.*** Surface drag will reduce winds at the surface, then winds will gradually increase with height away from the surface causing the smoke to disperse differently (slower) at the surface than aloft which can be important when considering a backing versus heading fire. Wind direction at the surface can also be very different than wind direction aloft. Thus, depending on smoke impact concerns, whether concerned about nearby sensitive receptors or receptors further downwind, both parameters should be noted. Topography can particularly influence the wind direction of surface winds as well, where winds may flow along a valley near the surface but be quite different aloft (away from the topographical influences). ***In valleys, there can be downslope flows due to surface cooling in the evening which is important if smoke is still being produced after dark and the drainage crosses a road.*** Similarly, in the morning there can be upslope flows from the valley with surface heating. All these factors are important for smoke dispersion.

Mixing Height

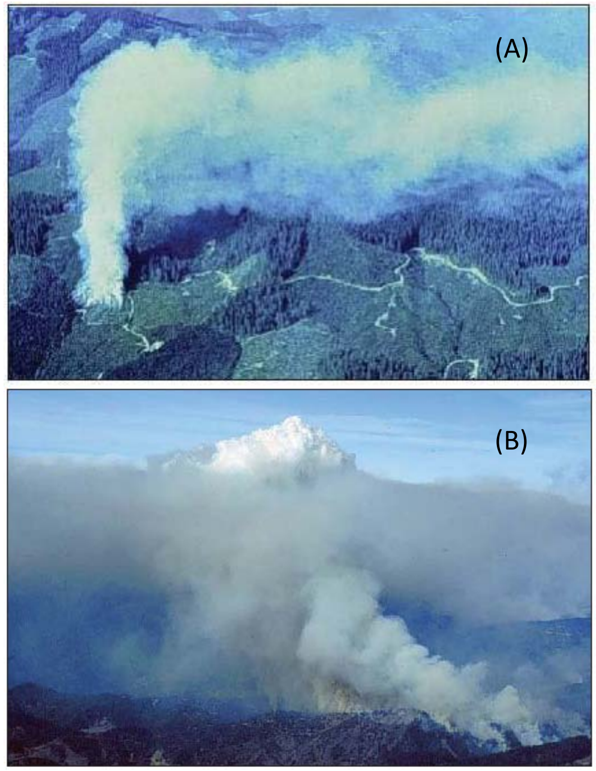
The mixing height is the height of the atmosphere above the ground which is well mixed due either to mechanical turbulence or convective turbulence. The air layer above this height is stable. The mixing height defines the depth of the mixed layer. Smoke released into the atmosphere has the potential to disperse vertically in the atmosphere up to the height of the mixing height depending on wind speed and atmospheric stability. ***A low mixing height can limit how the smoke disperses and can lead to greater smoke concentrations near the ground for longer periods of time.***

Ventilation Index (VENT)

Ventilation Index (VENT) is typically the product of the mixing height and the transport wind speed. The transport wind speed is typically the average wind speed through the mixed layer. By combining the two parameters of mixing height and transport wind into one Index, the dispersive potential of the atmosphere can be rated. Care should be taken to note when transport winds are high and mixing height is low because these conditions will keep smoke traveling close and confined to the surface. Conversely, when transport winds are low but mixing height is high, the smoke will loft high into the atmosphere (good dispersion) but fire behavior could be erratic and thus problematic. A single national scale does not exist for the ventilation or dispersion index so investigate your local implementation of this parameter.

Atmospheric Stability

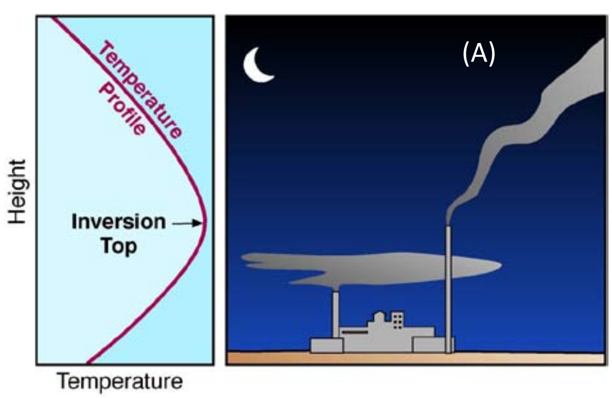
Atmospheric stability is a measure of the atmosphere's tendency to encourage or deter vertical motion. In unstable conditions, a lifted parcel of air will be warmer than the surrounding air at altitude. Because it is warmer, it is less dense and will continue to rise. Figure (A) is an example of ***smoke behavior in an unstable atmosphere – smoke is lofted away from the ground and transported downwind by the upper level winds. In a stable atmosphere the temperature of a rising parcel of air becomes cooler than its surroundings causing it to sink back to the surface, thus vertical motion is limited and smoke will tend to stay close to the surface.*** Figure (B) is an example of a stable atmosphere where smoke is fumigating the area beneath the mixing height and most vertical motion is due to the heat of the fire itself. Atmospheric stability can be estimated based on wind speed and solar insolation (Turner, 1994) on a scale of A (very unstable) to D (neutral) to F (very stable). Often the local NWS fire weather forecast will provide an estimation of atmospheric stability.

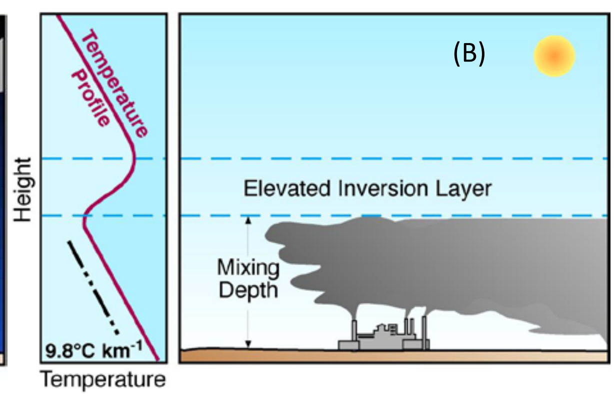


(photos by Roger Ottmar, USFS)

Atmospheric Vertical Temperature Profile and Inversions

The vertical temperature profile of the atmosphere is also related to atmospheric stability. On most days, the temperature of air in the atmosphere decreases with altitude. This is because most of the sun's energy is converted to sensible heat at the ground, which in turn warms the air at the surface. The warm air rises in the atmosphere, where it expands (due to lower pressure aloft) and cools. Sometimes, however, the temperature of air actually increases with height. The situation of having warm air on top of cooler air is referred to as a temperature inversion, because the temperature profile of the atmosphere is "inverted" from its usual state. There are two types of temperature inversions: surface inversions (Figure A) that occur near the Earth's surface, and aloft inversions (Figure B) that occur higher in the atmosphere. Figures used by permission from Whiteman (2000).





The most common manner in which surface inversions form is through the cooling of the air near the ground at night. Once the sun goes down, the ground loses heat very quickly, and this cools the air that is in contact with the ground. However, since air is a very poor conductor of heat, the air just above the surface remains warm. Conditions that favor the development of a strong surface inversion are calm winds, clear skies and long nights. Calm winds prevent warmer air above the surface from mixing down to the ground, and clear skies increase the rate of cooling at the Earth's surface. Long nights allow for the cooling of the ground to continue over a longer period of time, resulting in a greater temperature decrease at the surface. Since the nights in the wintertime are much longer than nights during the summertime, surface inversions are stronger and more common during the winter months. A strong inversion implies a substantial temperature difference exists between the cool surface air and the warmer air aloft. During the daylight hours, surface inversions normally weaken and disappear as the sun warms the Earth's surface. However, under certain meteorological conditions, such as strong high pressure over the area, these inversions can persist as long as several days. In addition, local topographical features can enhance the formation of inversions, especially in valley locations. Adapted from: http://www.wrh.noaa.gov/slc/climate/TemperatureInversions.php

Surface temperature inversions play a major role in how smoke disperses and in air quality conditions in general. The warm air above cooler air acts like a lid, suppressing vertical mixing and trapping the cooler air at the surface. ***If smoke is emitted into these conditions or is transported and trapped in the inversion then this can lead to poor air quality conditions.*** Care should be taken when burning during inversions or when one is expected to setup. Nighttime inversions can burn-off during the day therefore, depending on burn objectives and forecasted conditions, ignition during an inversion can be undertaken with caution and close monitoring. Also, if an inversion is expected to setup quickly post-burn (such as at night), it has the potential to trap smoke, and mitigation techniques such as mop-up can be employed to reduce the longer-term smoldering. In complex terrain, burning on slopes above an inversion can keep the smoke aloft and away from the valley floor (where roadways and communities are often located), but again, this should be undertaken with caution and close monitoring. ***Persistent (multiple-day) inversions in particular can create poor air quality conditions and burning under such conditions is not recommended.***

Water Vapor – Water Released from Fire and Atmospheric Water Content

As fuel is heated and combusted, water vapor is released into the atmosphere. This water can condense onto fine particulate matter from the 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 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 visibility to near zero.*** This phenomena and has been attributed to numerous traffic accidents (Achtemeier, 2003, Wade and Mobley, 2007). The Low Visibility Occurrence Risk Index (LVORI, Lavdas and Achtemeier, 1995) was developed based on relative humidity and the smoke dispersion index to be an indicator of potential fog occurrence. Values range from 1 - 10, where a LVORI of one means there is almost no chance of low visibility, and a LVORI of ten indicates low visibility is likely. For more information see: http://www.erh.noaa.gov/gsp/fire/ADI_LVORI/ADI_LVORI.html

National Weather Service (NWS) Fire Weather Information (http://radar.srh.noaa.gov/fire/): The National Weather Service Fire Weather webpage is a portal to local meteorological forecasts and observational data regarding many of the meteorological parameters discussed above. Below is an example of a NWS fire weather forecast for an area in Texas. In this case, information is given for near surface winds, cloud cover, transport winds, ventilation index and the category smoke dispersion day. The category day is based on the ventilation index and is on a scale of 1 to 5 where 1 is poor dispersion and 5 is excellent dispersion. Local/regional NWS offices typically customize the information to meet the needs of the area and can also do special spot forecasts. ***Use of these forecasts is a critical BSMP element.***

TXZ012-017-161100-
POTTER-RANDALL-
207 PM CDT FRI JUL 15 2011

	TONIGHT	SAT	SAT NIGHT	SUN
CLOUD COVER	MCLEAR	PCLDY	PCLDY	PCLDY
PRECIP TYPE	NONE	NONE	NONE	NONE
CHANCE PRECIP (%)	0	0	0	0
MAX/MIN TEMPERATURE	69	103	68	100
RELATIVE HUMIDITY %	61	18	61	21
20FT WND - AM (MPH)		S 9		S 10
20FT WND - PM (MPH)	S 14 G21	SE 12 G20	SE 14 G21	SE 13
PRECIP AMOUNT	0.00	0.00	0.00	0.00
LAL	1	1	1	1
HAINES INDEX	3	3	3	2
MIXING HGT (M-AGL)		4572		4115
MIXING HGT (FT-AGL)		15000		13500
TRANSPORT WND (M/S)		SE 6		SE 5
TRANSPORT WND (KTS)		SE 13		SE 12
VENT RATE (M*M/S)		25924		21211
VENT RATE (KT-FT)		165000		135000
CATEGORY DAY		5		5

Smoke Modeling

Smoke models provide a means of using meteorological and fuels information to give more detailed information about where and how smoke could disperse and the concentration of PM and other trace gases in the plume. A smoke modeling system essentially takes into account all the meteorological parameters described above along with on the ground fuels information to predict smoke dispersion, transport, and in some cases the trace gas chemical reactions. Smoke modeling is a more advanced feature that will be described in another Technical Note. Smoke modeling options are also summarized at: http://www.nifc.gov/smoke.