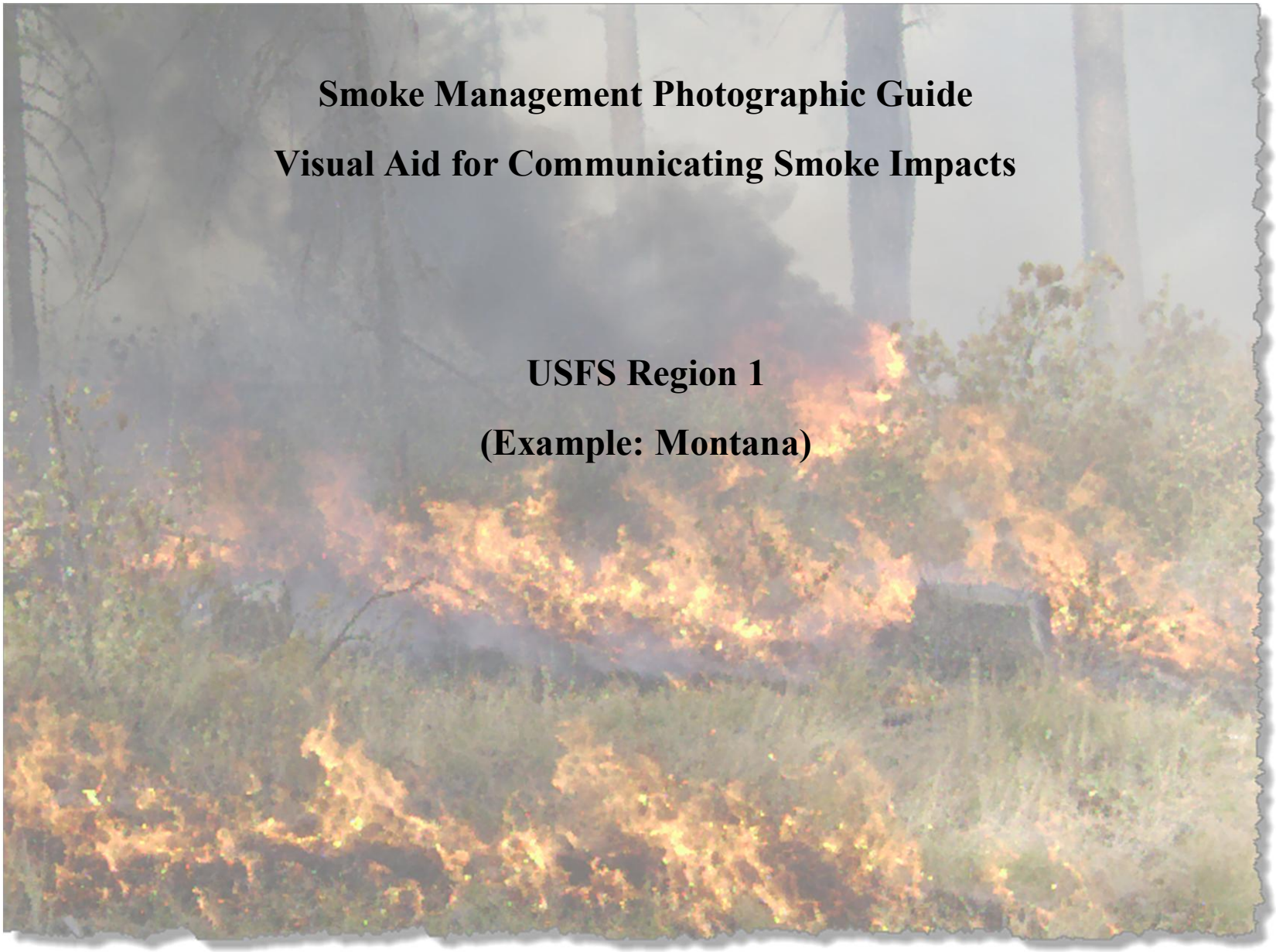


Smoke Management Photographic Guide

Visual Aid for Communicating Smoke Impacts

USFS Region 1

(Example: Montana)

University of Idaho
College of Natural Resources

Development and Scope:
This guide is developed by the University of Idaho College of Natural Resources with images from US National Park and USDA Forest Service locations.

The primary purpose of this guide is to serve as a tool for communicating potential particulate matter (PM 2.5) levels using visual representation. Numerous factors impact visibility; in addition to particulate matter and the presence of ozone (Aherns 2003), visibility is also affected by compounds including ammonium nitrate, ammonium sulfate, and light absorbing carbon (Malm *et al.* 1994), as well as relative humidity (Achtemeier et al. 2001). Existing background levels of visibility also vary across the country (Core 2001). This guide is intended to indicate smoky conditions in USFS Region 1. Due to the complexity of variables, and limitations in the distances perceived by the human eye, visual approximations should be used as indicators, not precise measurement.

Figure 1 The materials in this guide are for estimation purposes only and indented to represent the overall conditions in the highlighted regions.

Methods
To represent visual impacts from smoke in numerous locations across the Unites States this reference guide has been generated using WinHaze imaging software (Air Resource Specialists Inc. 2013). This software package incorporates several years of particulate data from Class I airsheds throughout the continental United States. The program allows for consistent visual representation of airsheds under varying humidity, background pollutant levels and particulate matter (PM) concentrations based on the IMPROVE equation for estimating ambient light extinction coefficients (Hand and Malm 2006). This methodology facilitates consistent representation of smoky conditions while avoiding variations in sun angle and camera placement that can occur using a more traditional method of matching photographs with monitoring data. Glacier National Park and the Bitterroot Valley were chosen for this guide. Data from Glacier National park was chosen based on 1037 days of particulate data incorporated into the visual estimates. To establish an image representing the area free of any smoke-impaired visibility a 'baseline' image was generated in WinHaze using the mean values indicated in the table on the left which total less than 5 $\mu g/m^3$ fine particulate matter and less than 5 $\mu g/m^3$ of coarse particulates.

Constituents of PM represented herein ($\mu g/m^3$)		
	Baseline	Elevated
Ammonium Sulfate	0.516	1.286
Ammonium Nitrate	0.127	0.608
Organic Carbon	1.012	-
LAC/Black Carbon	0.21	-
Fine Soil	0.177	1.187
Coarse mass	2.961	10.205

Visual impairment from smoke is simulated first by establishing constant values for the constituent of PM unlikely to change as the result of smoke from fires. 'Elevated' values for ammonium sulfate, ammonium nitrate, fine soil, and coarse mass were determined by using values recorded for the 20% worst visibility days. Organic carbon and Black carbon are then increased to reflect increasing concentrations of smoke, as this carbon composes nearly 75% of the emissions from forest fires (Andreae & Merlet 2001). The ratio of organic carbon to black carbon will be represented by a 15.4/1 ratio based on estimates for wildland fire in non-tropical forests in a comprehensive review by Andreae & Merlet (2001).

Because relative humidity (RH) impacts visibility and changes throughout the fire season, a range of different RH levels is represented based on morning and afternoon averages. Data for these averages is taken from Helena, MT (NOAA 2013). Values between the months of May and September were chosen to represent the relative humidity levels most likely to be present during the wildland fire season.

This guide represents short-term (1-3 hour) exposure pollutant levels as presented the Wildfire Smoke, A Guide for Public Health Officials (Lipset *et al.* 2008). The categories ('Good', 'Moderate', etc.) use terminology based on the EPA's Air Quality Index (US EPA, 2009). Due to the difficulty of distinguishing a fine scale measurement such as particulate concentration by using eyesight alone, three values were chosen, each in the mid-range of a health effect index category (*below*).

EPA Values for PM		Concentrations	
AQI Value	Actions to protect your health from particle pollution	PM2.5 or PM10 Levels ($\mu g/m^3$) 1 to 3 hour average	
Good (0-50)	None	0-38	19 $\mu g/m^3$
Moderate (51-100)	Unusually sensitive people should consider reducing prolonged or heavy exertion.	39-88	
Unhealthy for Sensitive Groups 101-150	The following groups should reduce prolonged or heavy outdoor exertion: -People with heart or lung disease -Children and older adults Everyone else should limit prolonged or heavy exertion	89-138	114 $\mu g/m^3$
Unhealthy (151-200)	The following groups should avoid all physical outdoors: -People with heart or lung disease -Children and older adults Everyone else should avoid prolonged or heavy exertion	139-351	245 $\mu g/m^3$
Very Unhealthy (201-300)	The following groups should remain indoors and keep activity levels low: -People with heart or lung disease -Children and older adults Everyone else should avoid all physical activity outdoors	352-526+	

Using this guide:

To use this guide to represent particulate matter, compare your line of site with landmarks similar distances as those depicted here-in. When making this comparison, face away from the sun. Use points on the landscape of known distances that you are familiar with. Several examples of the same concentration are represented with varying relative humilities based on what is likely to be encountered during the fire season.

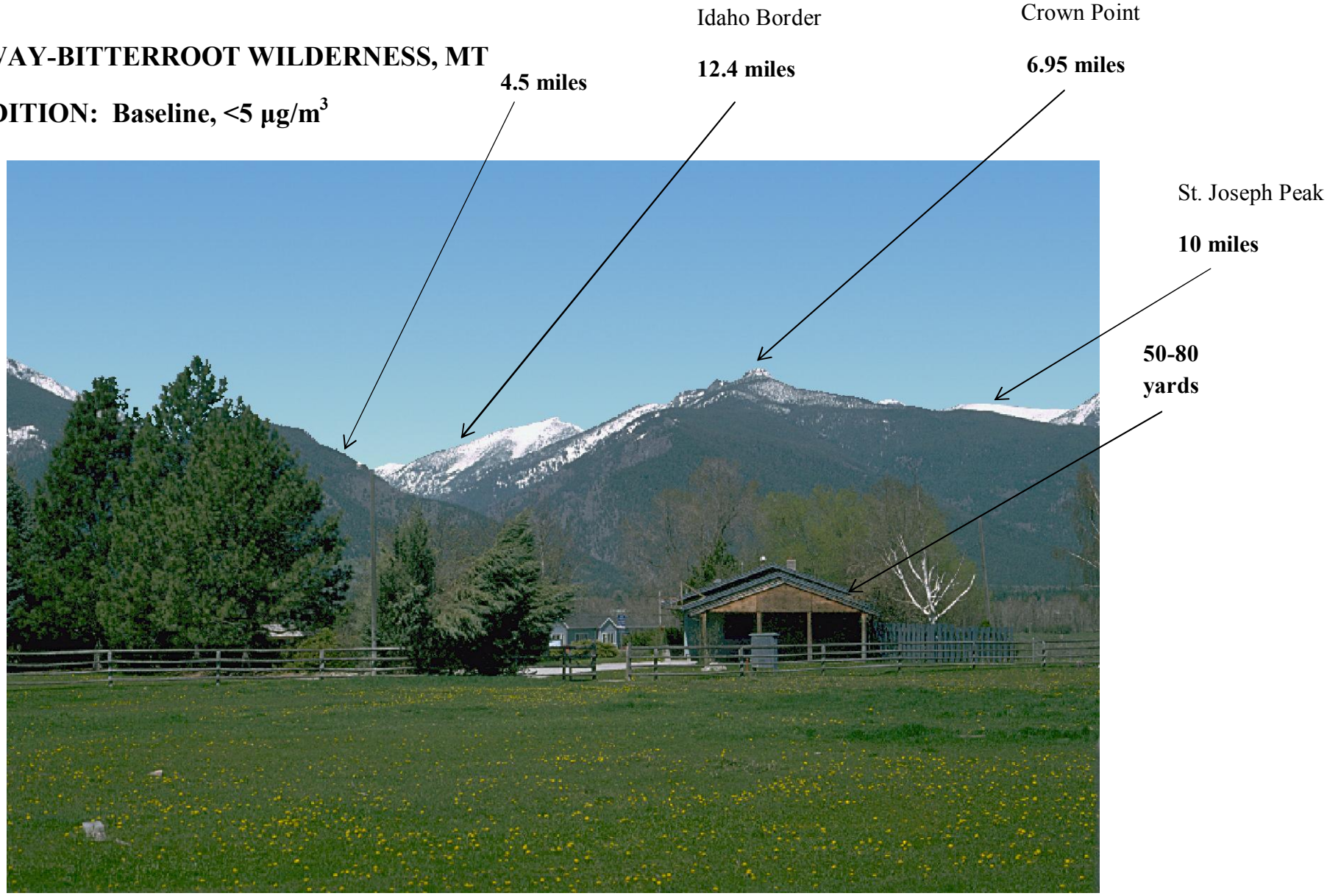
SELWAY-BITTERROOT WILDERNESS, MT

CONDITION: 19 µg/m³

PM 2.5	**19 µg/m³**
Relative Humidity	**20%**
Visual Range	**29.2 miles**

SELWAY-BITTERROOT WILDERNESS, MT

CONDITION: Baseline, <5 µg/m^3



PM 2.5	**< 5 µg/m^3**
Relative Humidity	**20 %**
Visual Range	**121.8 miles**

SELWAY-BITTERROOT WILDERNESS, MT

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**20% - 30%**
Visual Range	**26.3 miles**

SELWAY-BITTERROOT WILDERNESS, MT

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**40 %**
Visual Range	**26.2 miles**

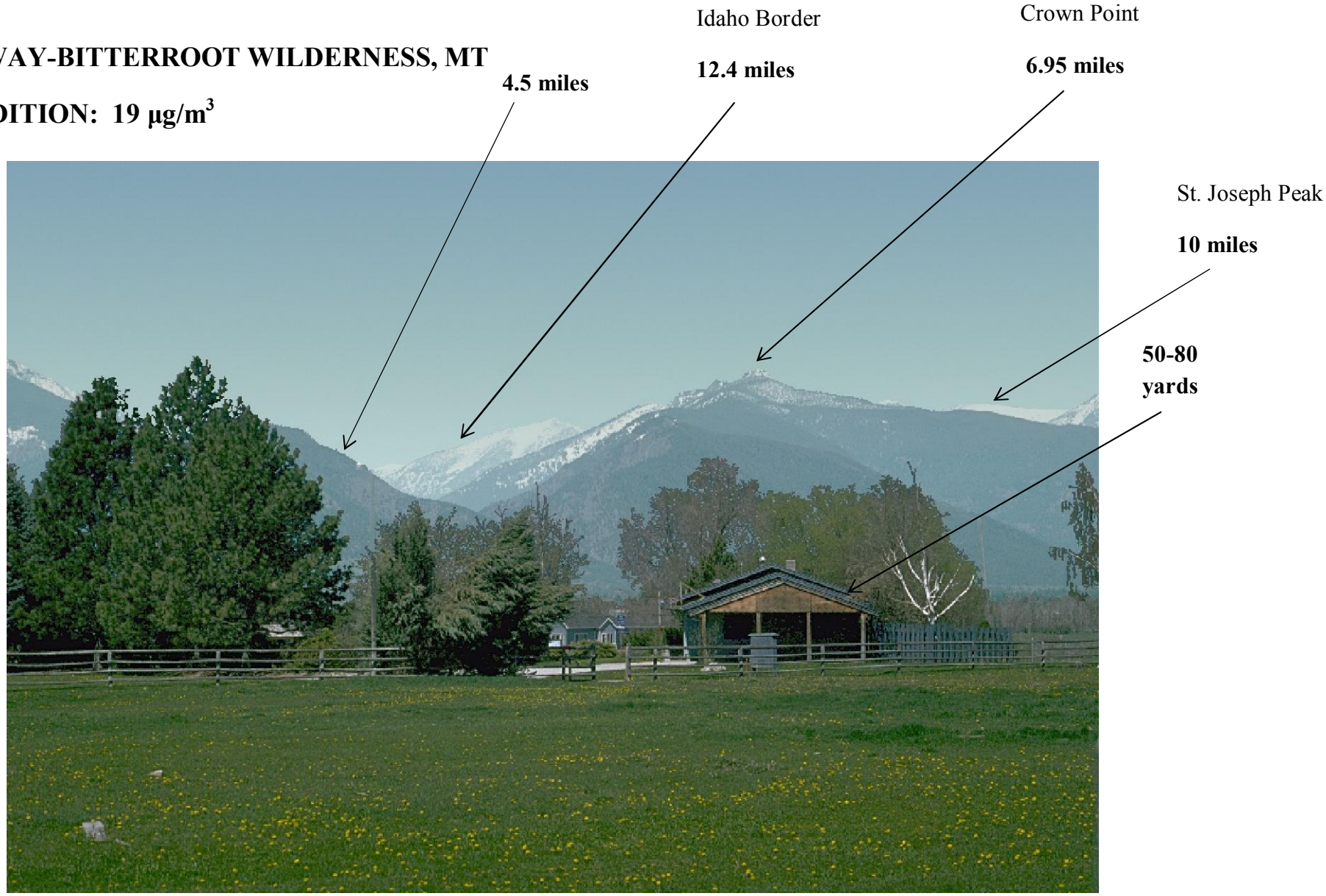
SELWAY-BITTERROOT WILDERNESS, MT

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**50 %**
Visual Range	**25.8 miles**

SELWAY-BITTERROOT WILDERNESS, MT

CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**60%**
Visual Range	**25.3 miles**

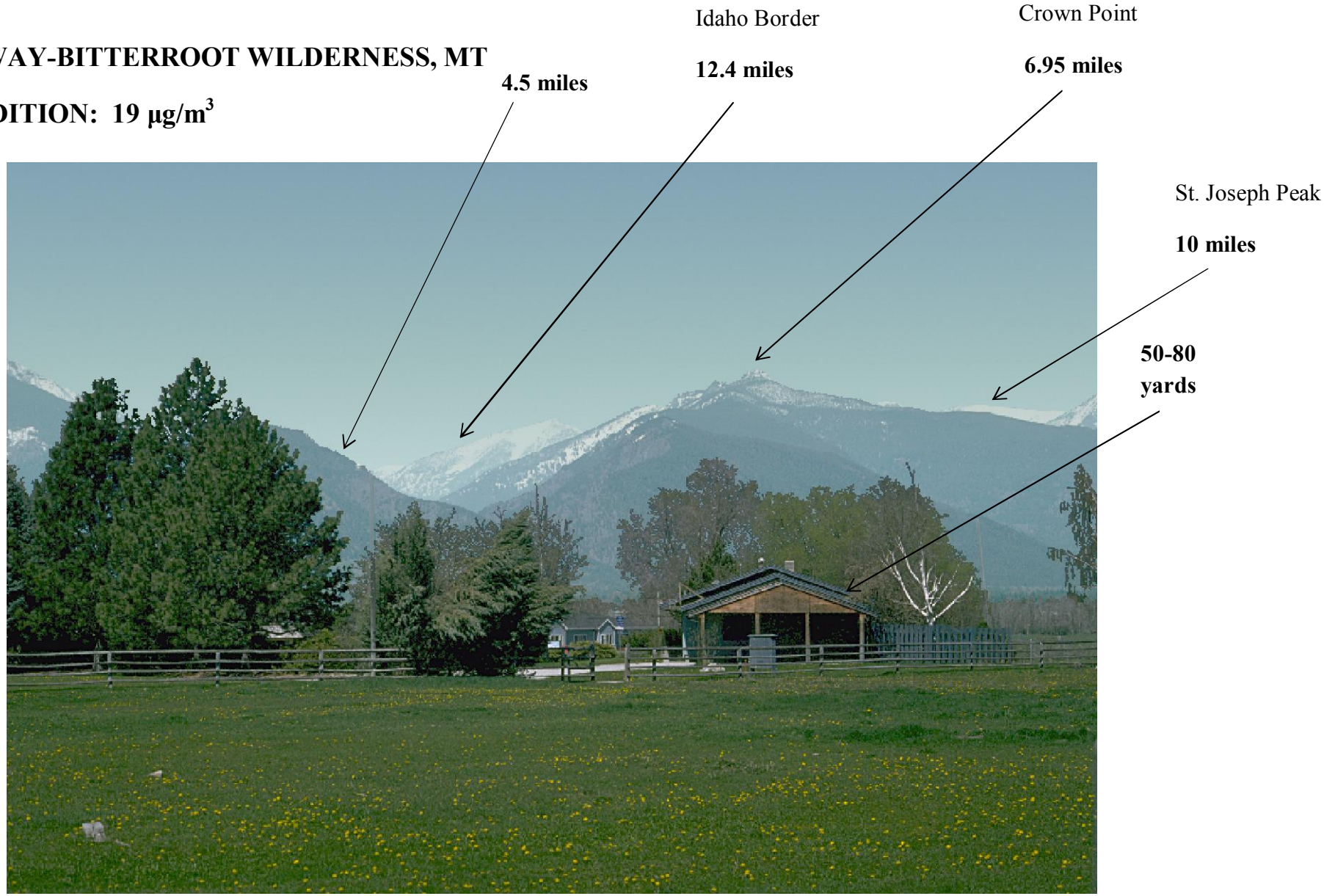
SELWAY-BITTERROOT WILDERNESS, MT

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**70%**
Visual Range	**24.6 miles**

SELWAY-BITTERROOT WILDERNESS, MT

CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**80%**
Visual Range	**23.8 miles**

SELWAY-BITTERROOT WILDERNESS, MT

CONDITION: 114 µg/m^3

PM 2.5	**114 µg/m^3**
Relative Humidity	**20% - 60%**
Visual Range	**4.8 miles**

SELWAY-BITTERROOT WILDERNESS, MT

CONDITION: 114 µg/m^3

PM 2.5	**114 µg/m^3**
Relative Humidity	**70% - 80%**
Visual Range	**4.7 miles**

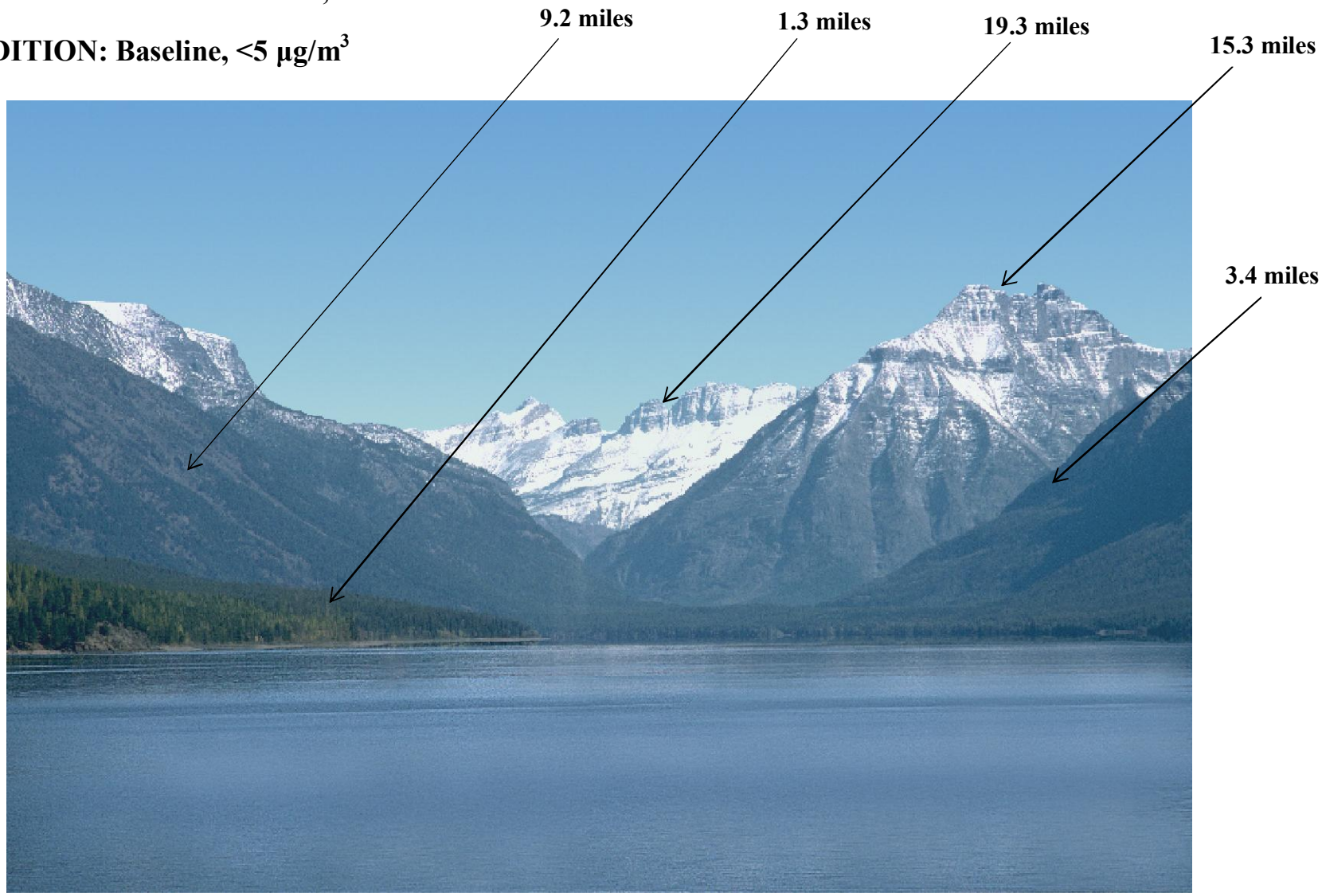
SELWAY-BITTERROOT WILDERNESS, MT

CONDITION: 245 µg/m^3

PM 2.5	**245 µg/m^3**
Relative Humidity	**20% - 80%**
Visual Range	**2.2 miles**

GLACIER NATIONAL PARK, MT

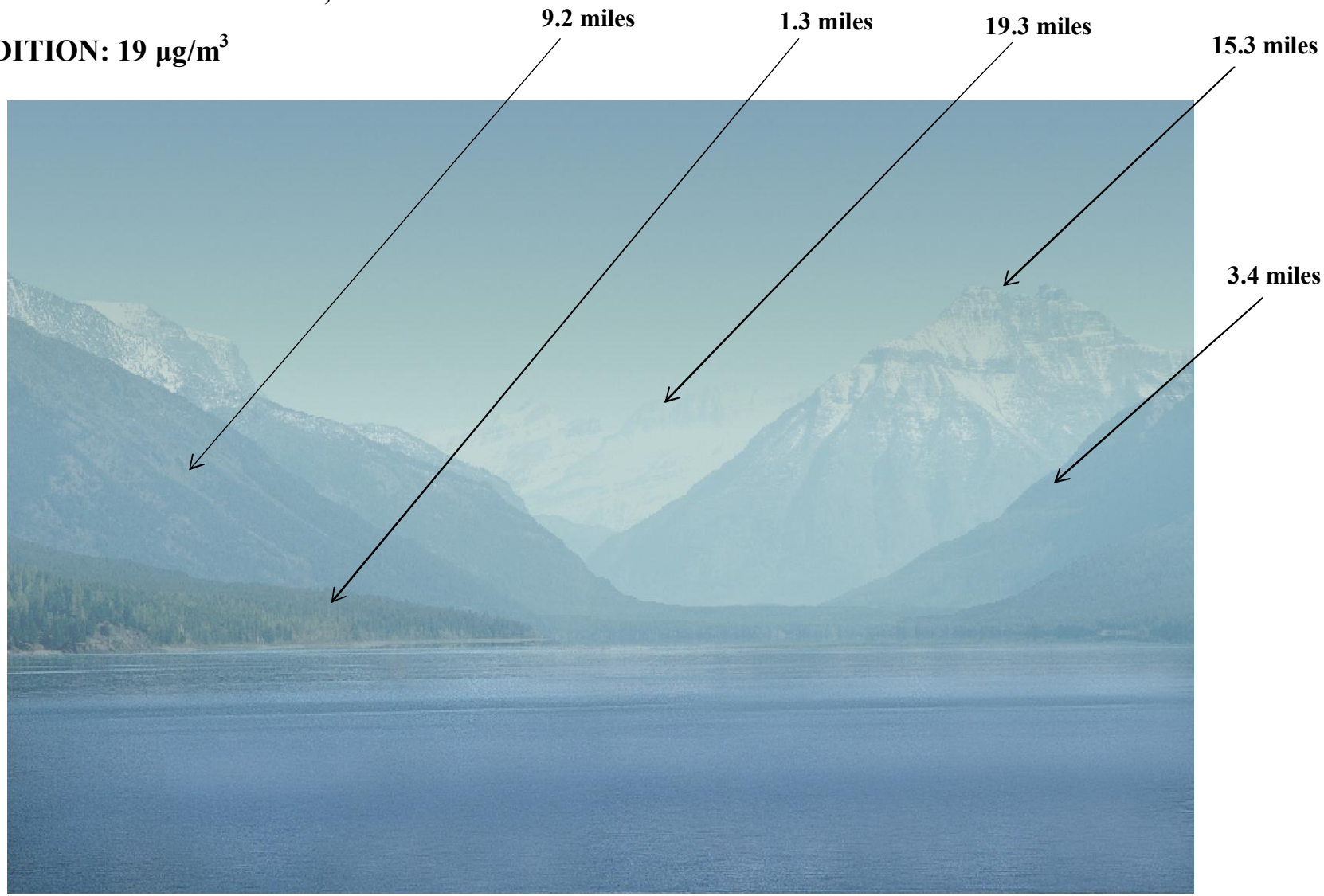
CONDITION: Baseline, <5 µg/m^3



PM 2.5	**< 5 µg/m^3**
Relative Humidity	**20 %**
Visual Range	**121.8 miles**

GLACIER NATIONAL PARK, MT

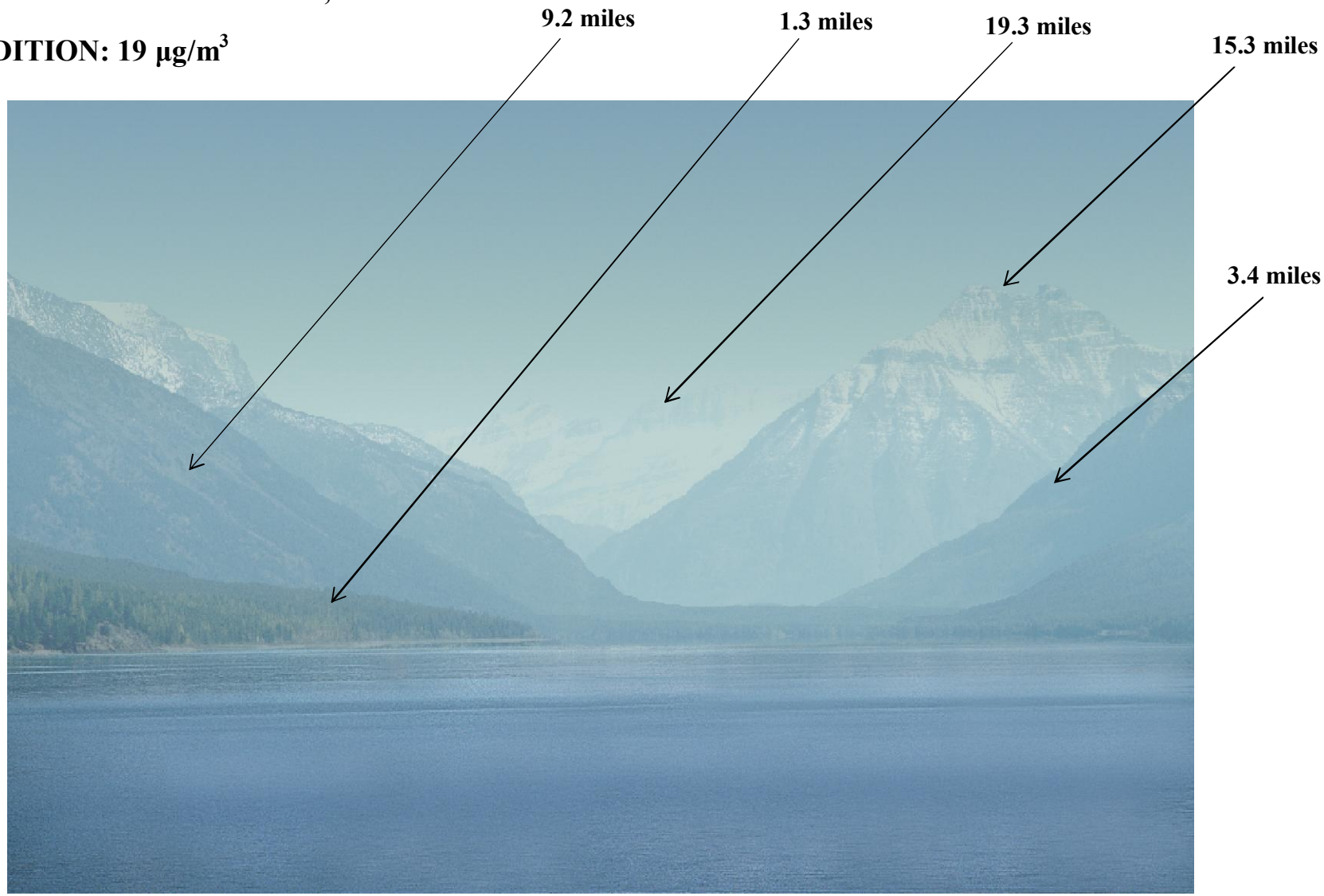
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**20% - 30%**
Visual Range	**26.3miles**

GLACIER NATIONAL PARK, MT

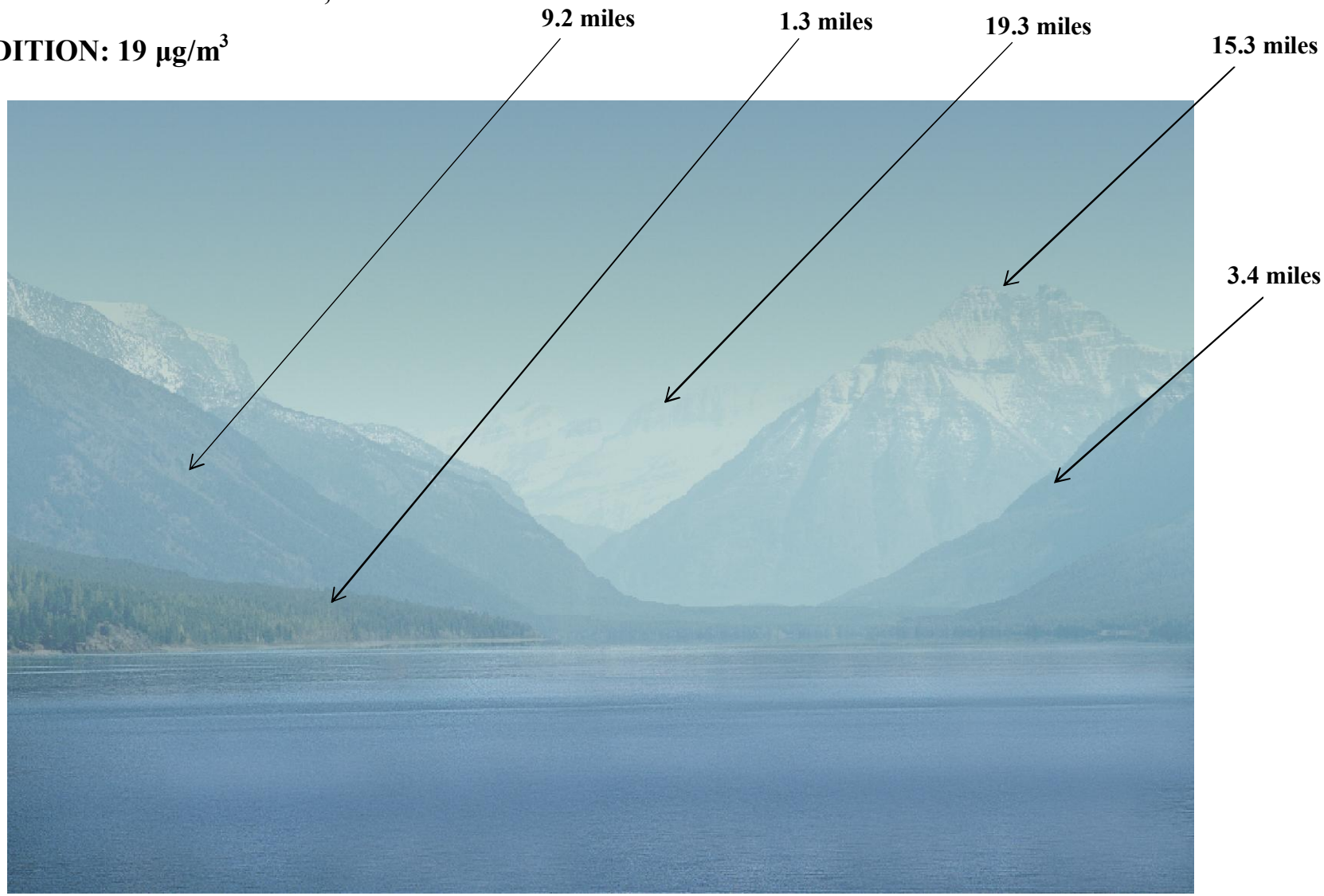
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**40 %**
Visual Range	**26.2miles**

GLACIER NATIONAL PARK, MT

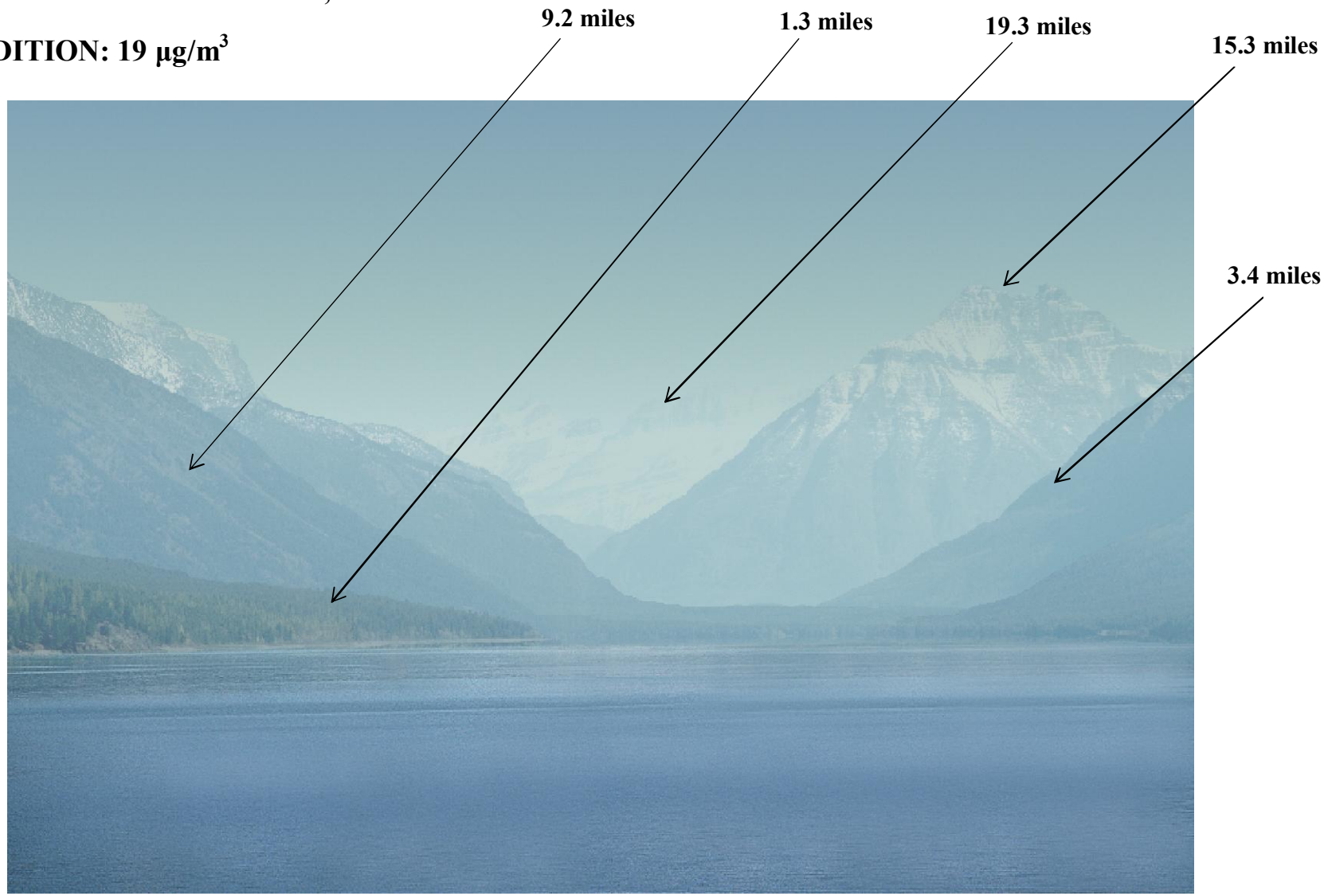
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**50 %**
Visual Range	**25.8 miles**

GLACIER NATIONAL PARK, MT

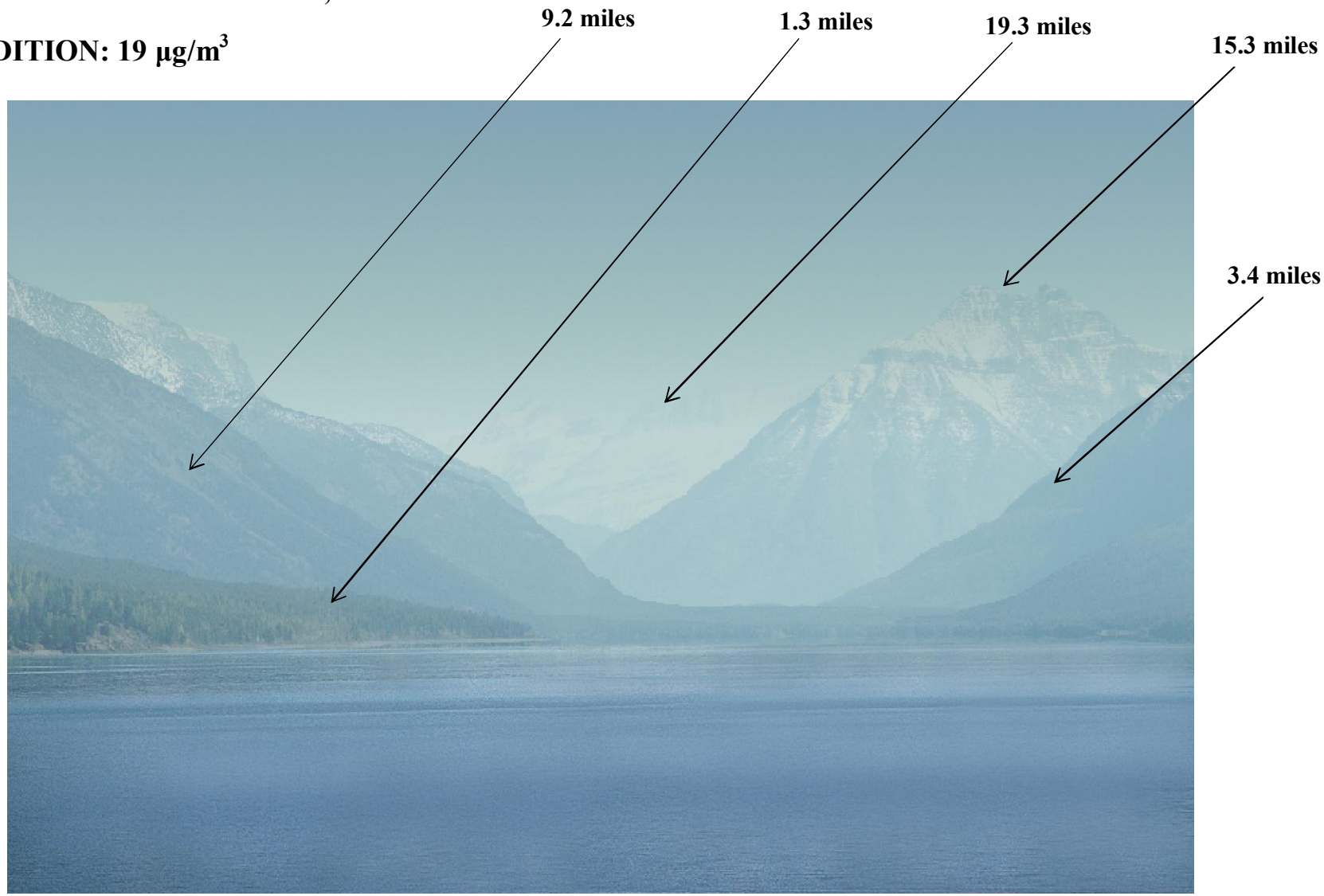
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**60 %**
Visual Range	**25.3 miles**

GLACIER NATIONAL PARK, MT

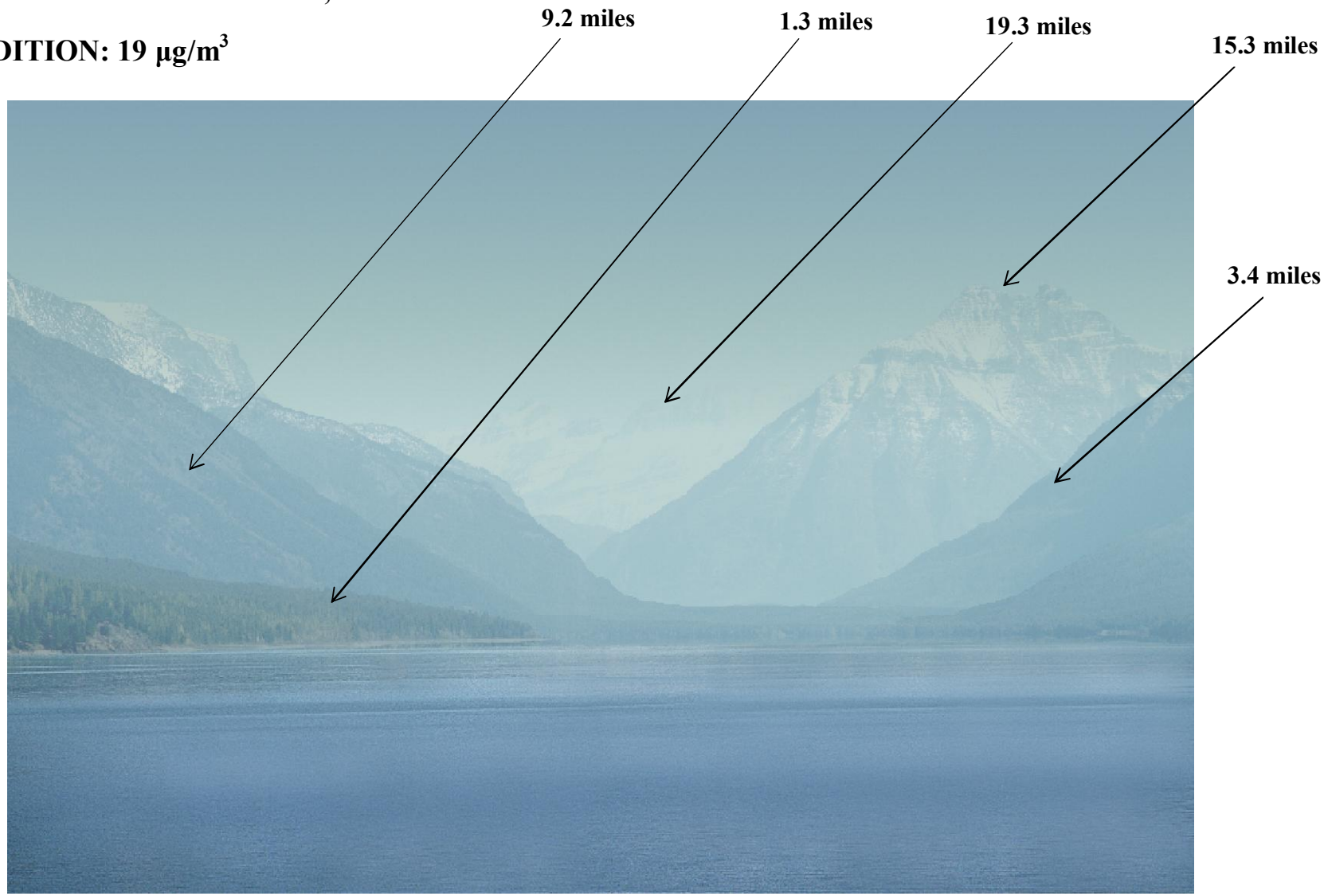
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**70 %**
Visual Range	**24.6 miles**

GLACIER NATIONAL PARK, MT

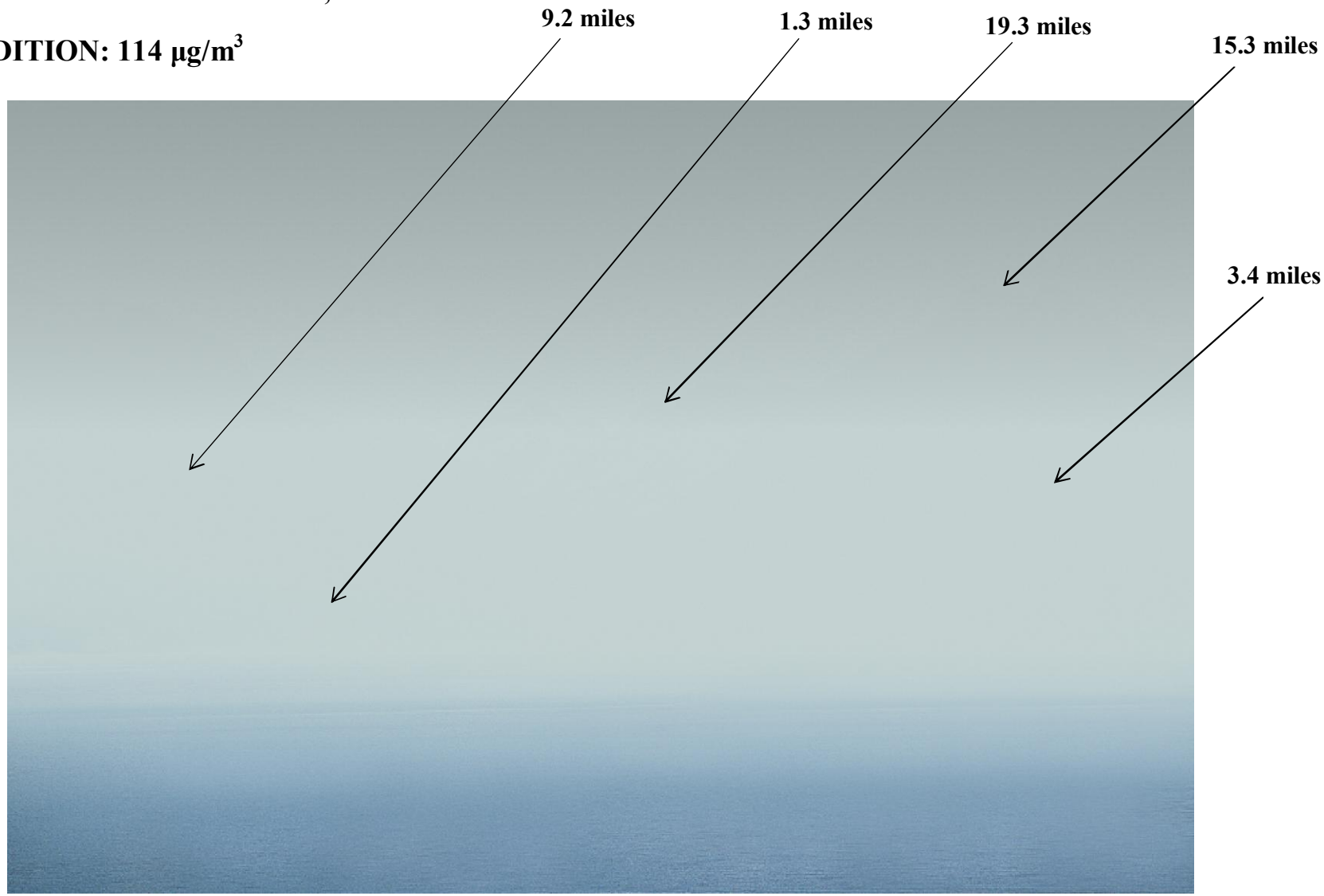
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**80 %**
Visual Range	**23.8 miles**

GLACIER NATIONAL PARK, MT

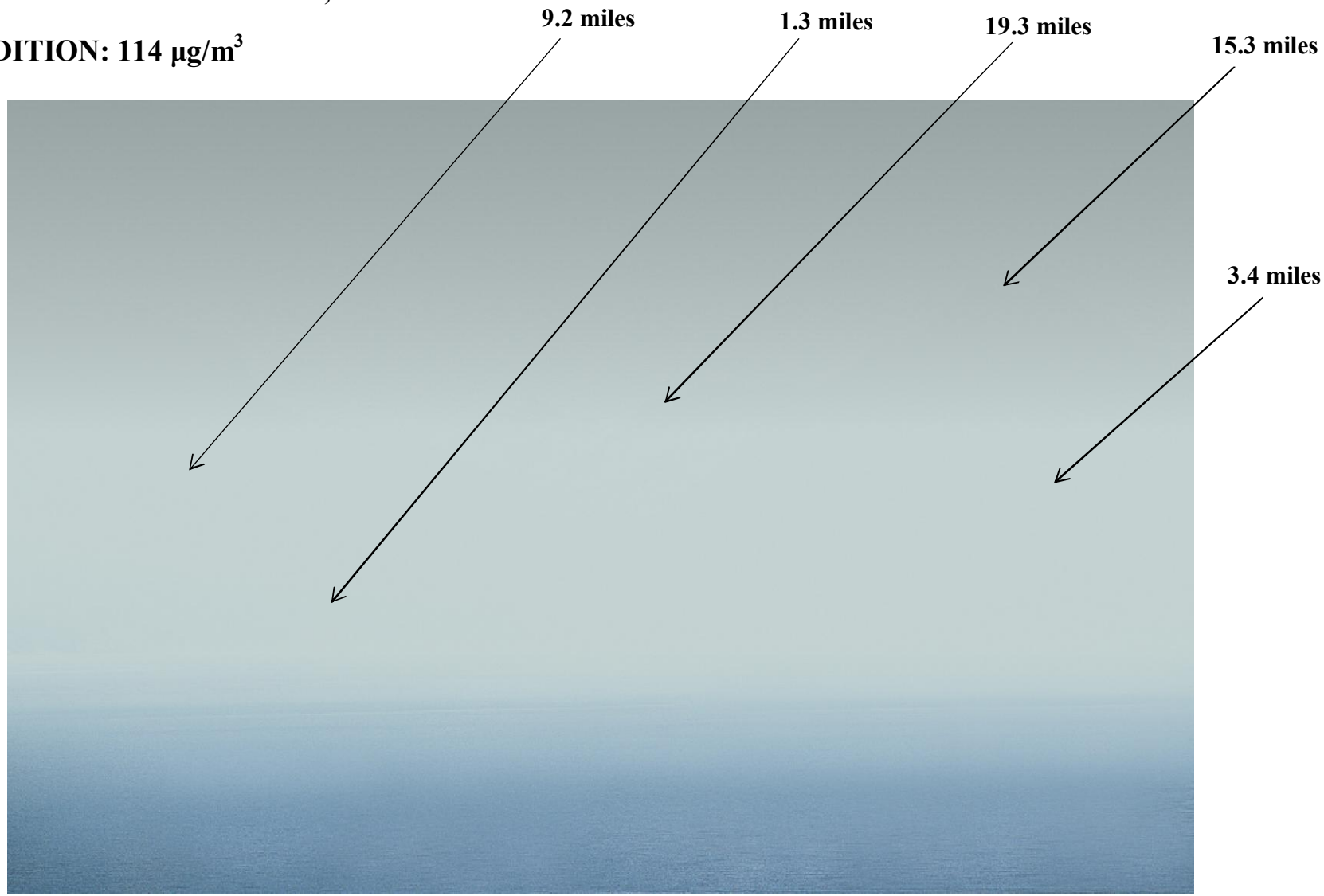
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**20% - 60%**
Visual Range	**4.8 miles**

GLACIER NATIONAL PARK, MT

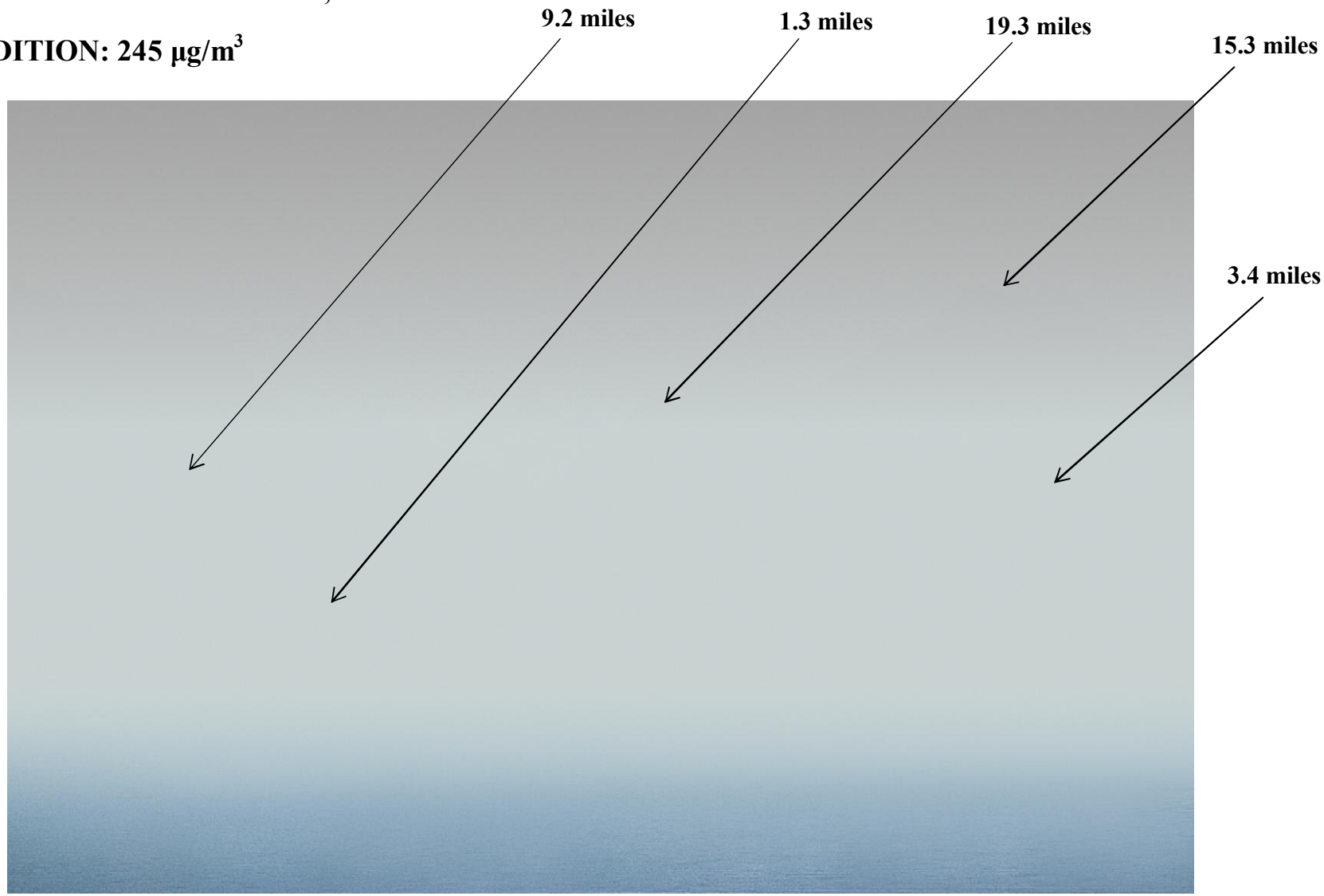
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**70% - 80%**
Visual Range	**4.7 miles**

GLACIER NATIONAL PARK, MT

CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**20 % and above**
Visual Range	**2.2 miles or less**

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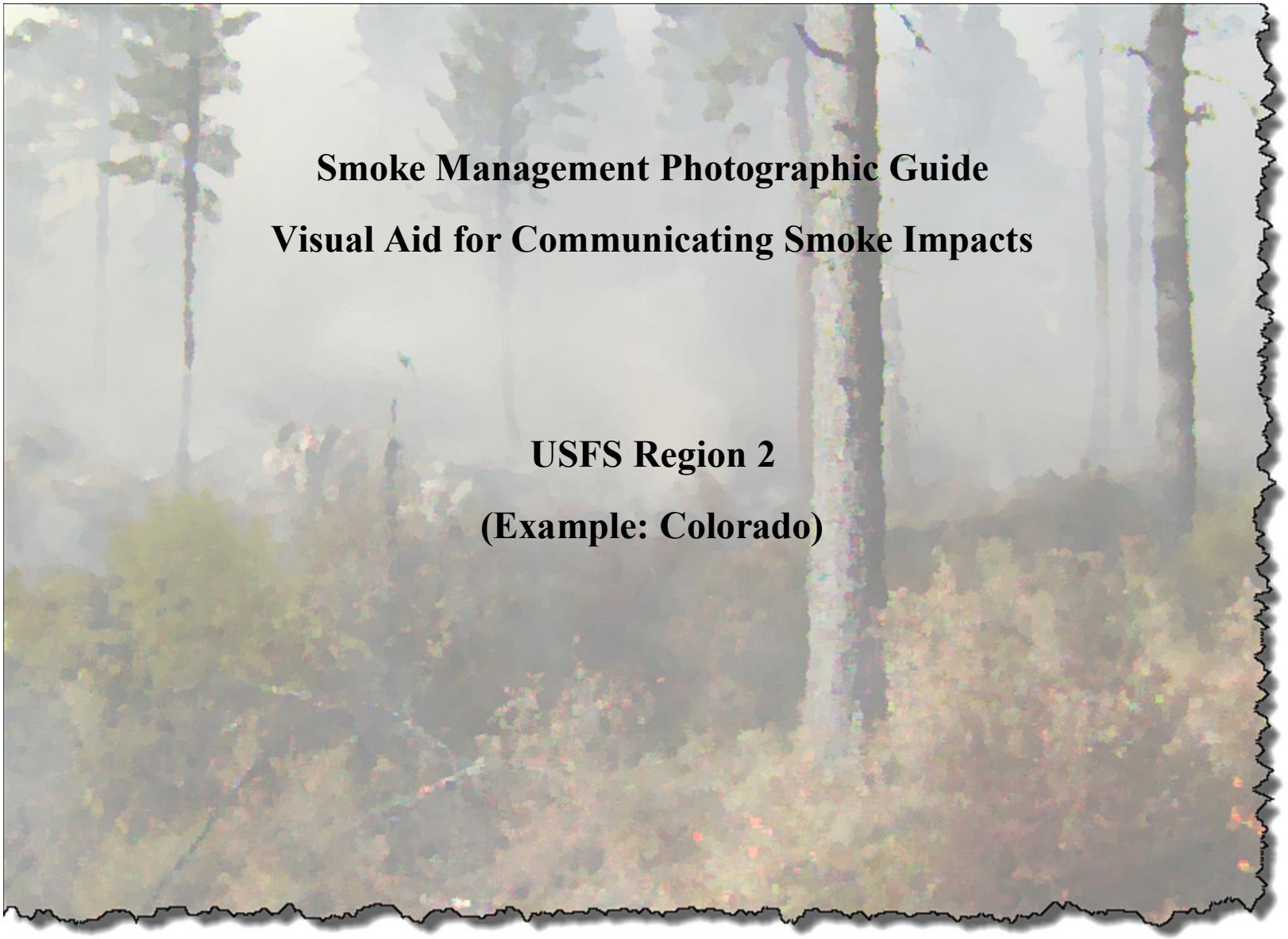


Smoke Management Photographic Guide

Visual Aid for Communicating Smoke Impacts

USFS Region 2

(Example: Colorado)

University of Idaho
College of Natural Resources

Development and Scope:
This guide is developed by the University of Idaho College of Natural Resources with images from US National Park and USDA Forest Service locations.

The primary purpose of this guide is to serve as a tool for communicating potential particulate matter (PM 2.5) levels using visual representation. Numerous factors impact visibility; in addition to particulate matter and the presence of ozone (Aherns 2003), visibility is also affected by compounds including ammonium nitrate, ammonium sulfate, and light absorbing carbon (Malm *et al.* 1994), as well as relative humidity (Achtemeier et al. 2001). Existing background levels of visibility also vary across the country (Core 2001). This guide is intended to indicate smoky conditions in USFS Region 2. Due to the complexity of variables, and limitations in the distances perceived by the human eye, visual approximations should be used as indicators, not precise measurement.

Figure 1 The materials in this guide are for estimation purposes only and indented to represent the overall conditions in the highlighted regions.

Methods
To represent visual impacts from smoke in numerous locations across the Unites States this reference guide has been generated using WinHaze imaging software (Air Resource Specialists Inc. 2013). This software package incorporates several years of particulate data from Class I airsheds throughout the continental United States. The program allows for consistent visual representation of airsheds under varying humidity, background pollutant levels and particulate matter (PM) concentrations based on the IMPROVE equation for estimating ambient light extinction coefficients (Hand and Malm 2006). This methodology facilitates consistent representation of smoky conditions while avoiding variations in sun angle and camera placement that can occur using a more traditional method of matching photographs with monitoring data. Rocky Mountains National Park was chosen for this guide based on7941 days of particulate data incorporated into the visual estimates. To establish an image representing the area free of any smoke-impaired visibility a 'baseline' image was generated in WinHaze using the mean values indicated in the table on the left which total less than 5 µg/m^3 fine particulate matter and less than 5 µg/m^3 of coarse particulates.

Constituents of PM represented herein (µg/m^3)		
	Baseline	Elevated
Ammonium Sulfate	0.33	1.49
Ammonium Nitrate	0.05	0.5
Organic Carbon	0.42	-
LAC/Black Carbon	0.11	-
Fine Soil	0.18	2.18
Coarse mass	2.94	5.88

Visual impairment from smoke is simulated first by establishing constant values for the constituent of PM unlikely to change as the result of smoke from fires. 'Elevated' values for ammonium sulfate, ammonium nitrate, fine soil, and coarse mass were determined by using values recorded for the 20% worst visibility days. Organic carbon and Black carbon are then increased to reflect increasing concentrations of smoke, as this carbon

composes nearly 75% of the emissions from forest fires (Andreae & Merlet 2001). The ratio of organic carbon to black carbon will be represented by a 15.3/1 ratio based on estimates for wildland fire in non-tropical forests in a comprehensive review by Andreae & Merlet (2001).

Because relative humidity (RH) impacts visibility and changes throughout the fire season, a range of different RH levels is represented based on morning and afternoon averages. Data for these averages is taken from Denver, CO(NOAA 2013). Values between the months of May and September were chosen to represent the relative humidity levels most likely to be present during the wildland fire season.

This guide represents short-term (1-3 hour) exposure pollutant levels as presented the Wildfire Smoke, A Guide for Public Health Officials (Lipset *et al.* 2008). The categories ('Good', 'Moderate', etc.) use terminology based on the EPA's Air Quality Index (US EPA, 2009). Due to the difficulty of distinguishing a fine scale measurement such as particulate concentration by using eyesight alone, three values were chosen, each in the mid-range of a health effect index category (*below*).

EPA Values for PM		Concentrations
AQI Value	Actions to protect your health from particle pollution	PM2.5 or PM10 Levels ($\mu g/m^3$) 1 to 3 hour average
Good (0-50)	None	0-38
Moderate (51-100)	Unusually sensitive people should consider reducing prolonged or heavy exertion.	39-88
Unhealthy for Sensitive Groups 101-150	The following groups should reduce prolonged or heavy outdoor exertion: -People with heart or lung disease -Children and older adults Everyone else should limit prolonged or heavy exertion	89-138
Unhealthy (151-200)	The following groups should avoid all physical outdoors: -People with heart or lung disease -Children and older adults Everyone else should avoid prolonged or heavy exertion	139-351
Very Unhealthy (201-300)	The following groups should remain indoors and keep activity levels low: -People with heart or lung disease -Children and older adults Everyone else should avoid all physical activity outdoors	352-526+

19 $\mu g/m^3$

114 $\mu g/m^3$

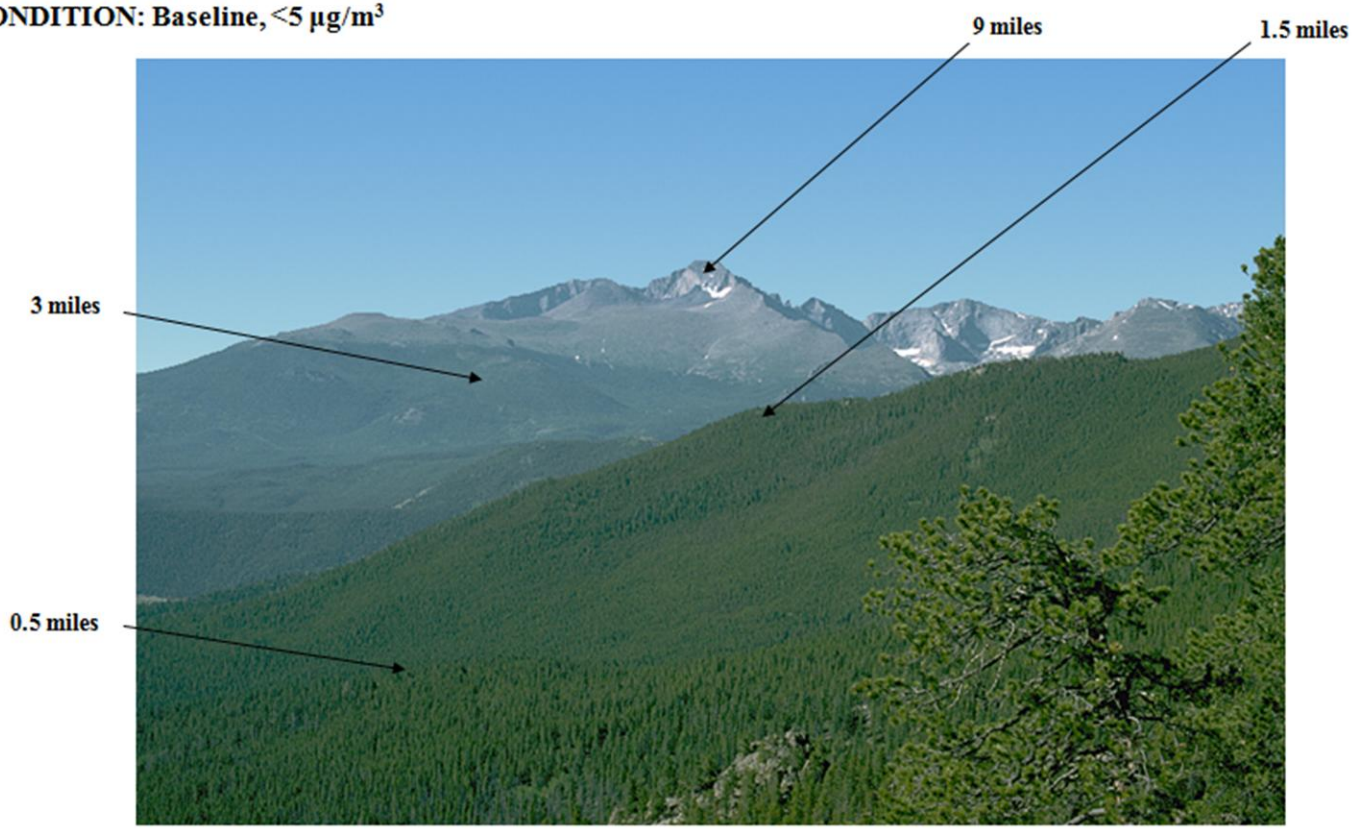
245 $\mu g/m^3$

Using this guide:

To use this guide to represent particulate matter, compare your line of site with landmarks similar distances as those depicted here-in. When making this comparison, face away from the sun. Use points on the landscape of known distances that you are familiar with. Several examples of the same concentration are represented with varying relative humilities based on what is likely to be encountered during the fire season.

ROCKY MOUNTAIN NATIONAL PARK, CO

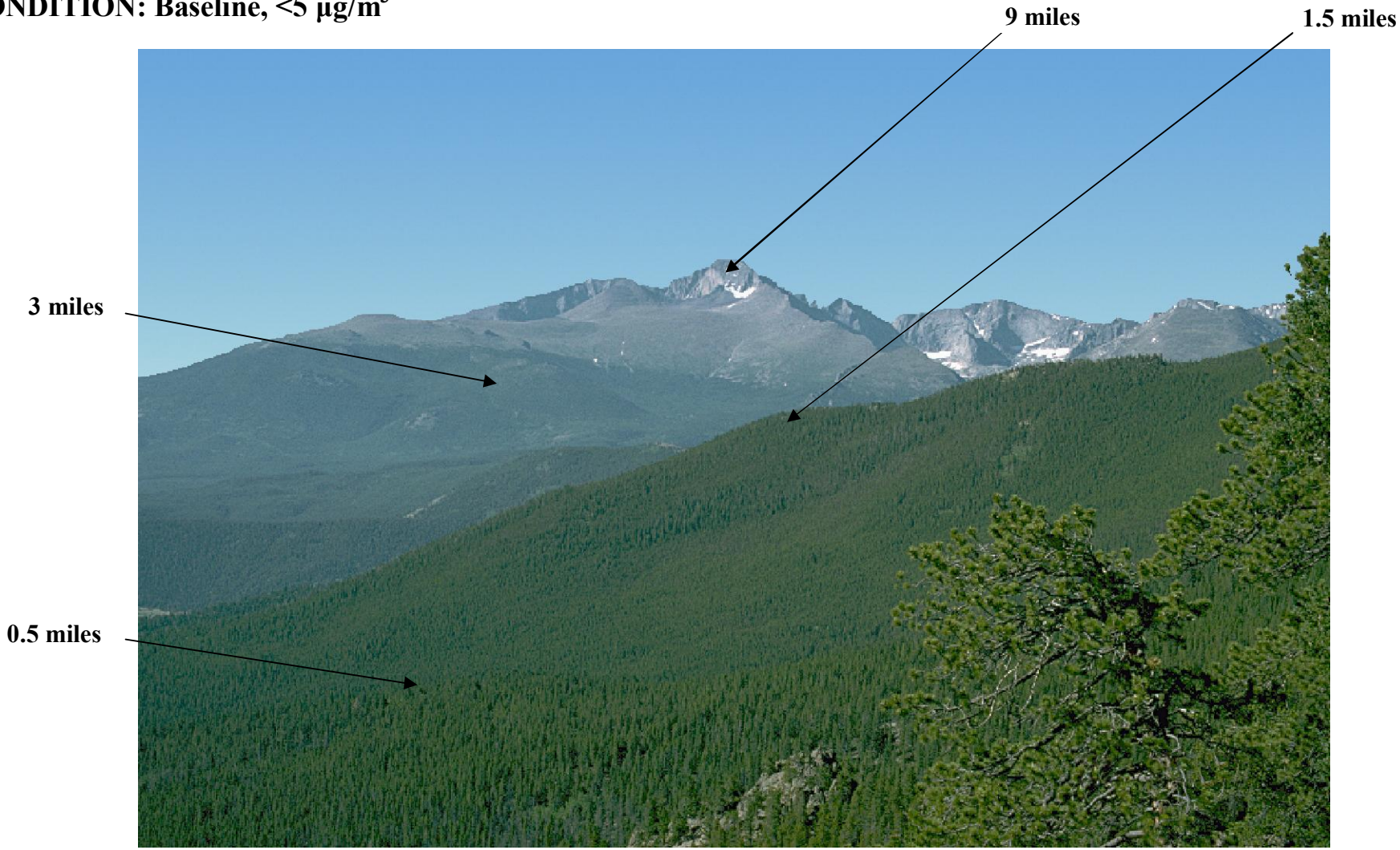
CONDITION: Baseline, <5 µg/m³



PM 2.5	**<5.0 µg/m³**
Relative Humidity	**30%**
Visual Range	**152.9 miles**

ROCKY MOUNTAIN NATIONAL PARK, CO

CONDITION: Baseline, <5 µg/m^3



PM 2.5	**<5.0 µg/m^3**
Relative Humidity	**30%**
Visual Range	**152.9 miles**

ROCKY MOUNTAIN NATIONAL PARK, CO

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**30%**
Visual Range	**27.3 miles**

ROCKY MOUNTAIN NATIONAL PARK, CO

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**40%**
Visual Range	**27.2 miles**

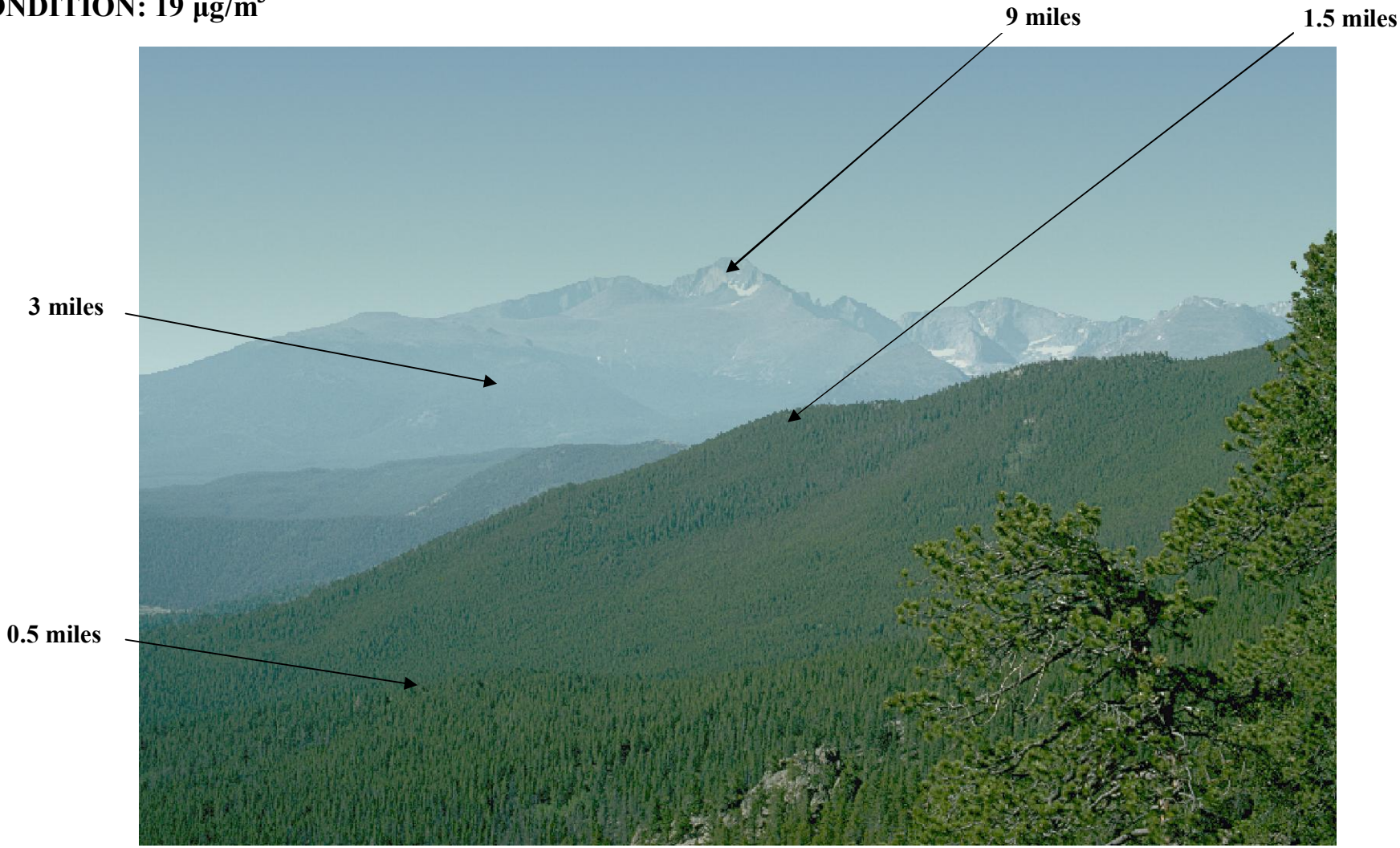
ROCKY MOUNTAIN NATIONAL PARK, CO

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**50%**
Visual Range	**25.7 miles**

ROCKY MOUNTAIN NATIONAL PARK, CO

CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**60%**
Visual Range	**26.1 miles**

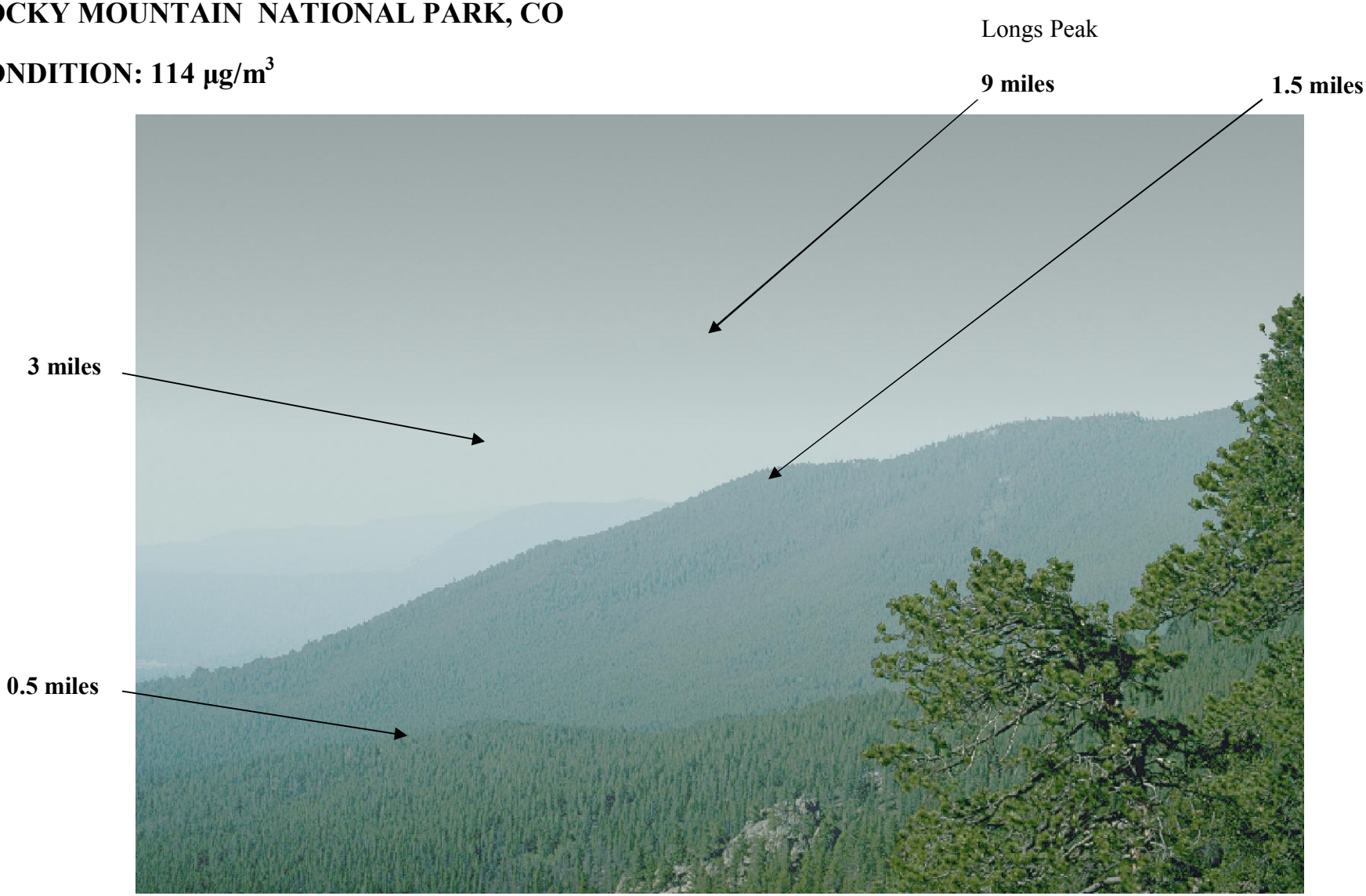
ROCKY MOUNTAIN NATIONAL PARK, CO

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**70 %**
Visual Range	**25.4 miles**

ROCKY MOUNTAIN NATIONAL PARK, CO

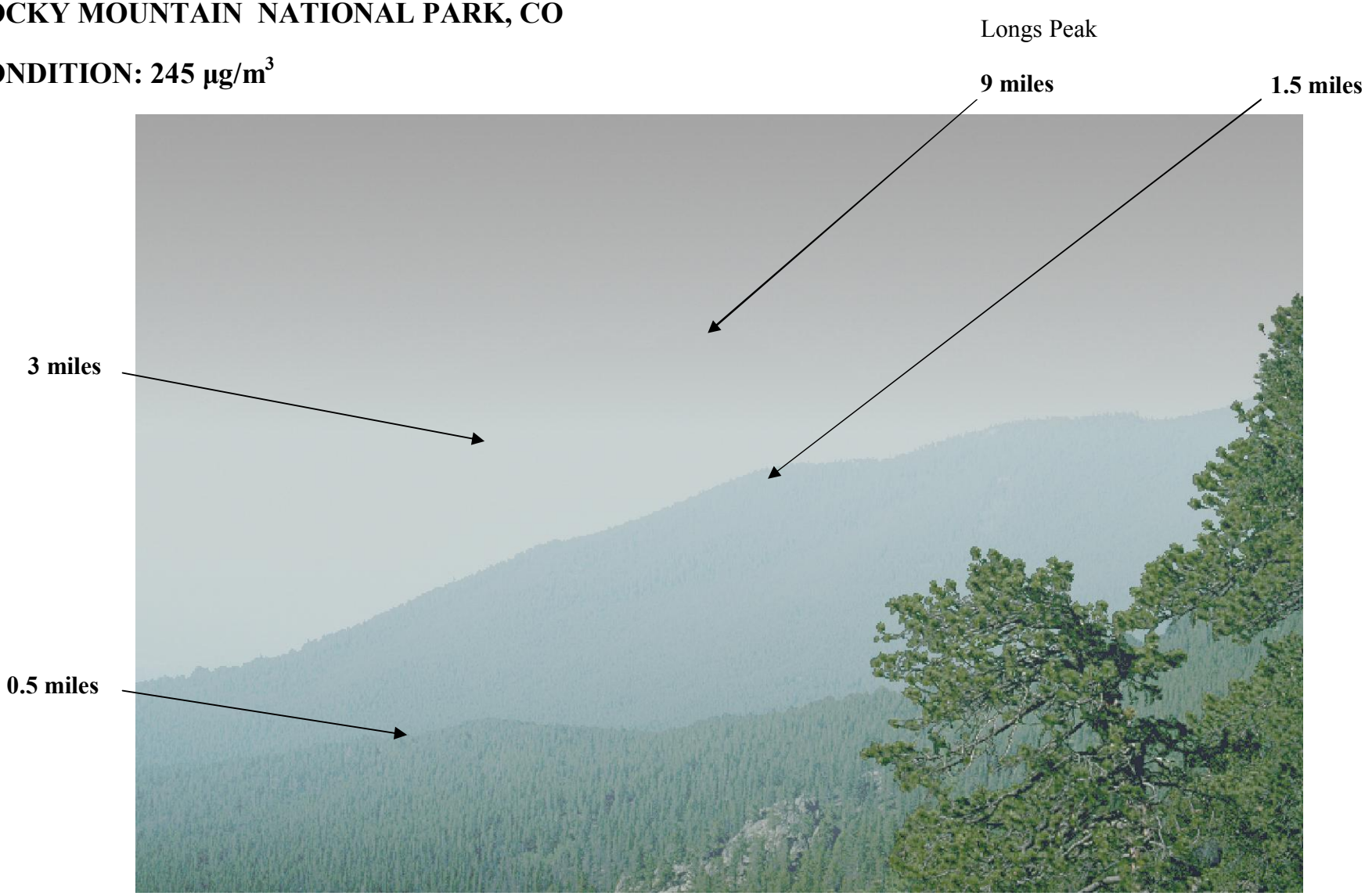
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**30% - 70%**
Visual Range	**4.8 miles**

ROCKY MOUNTAIN NATIONAL PARK, CO

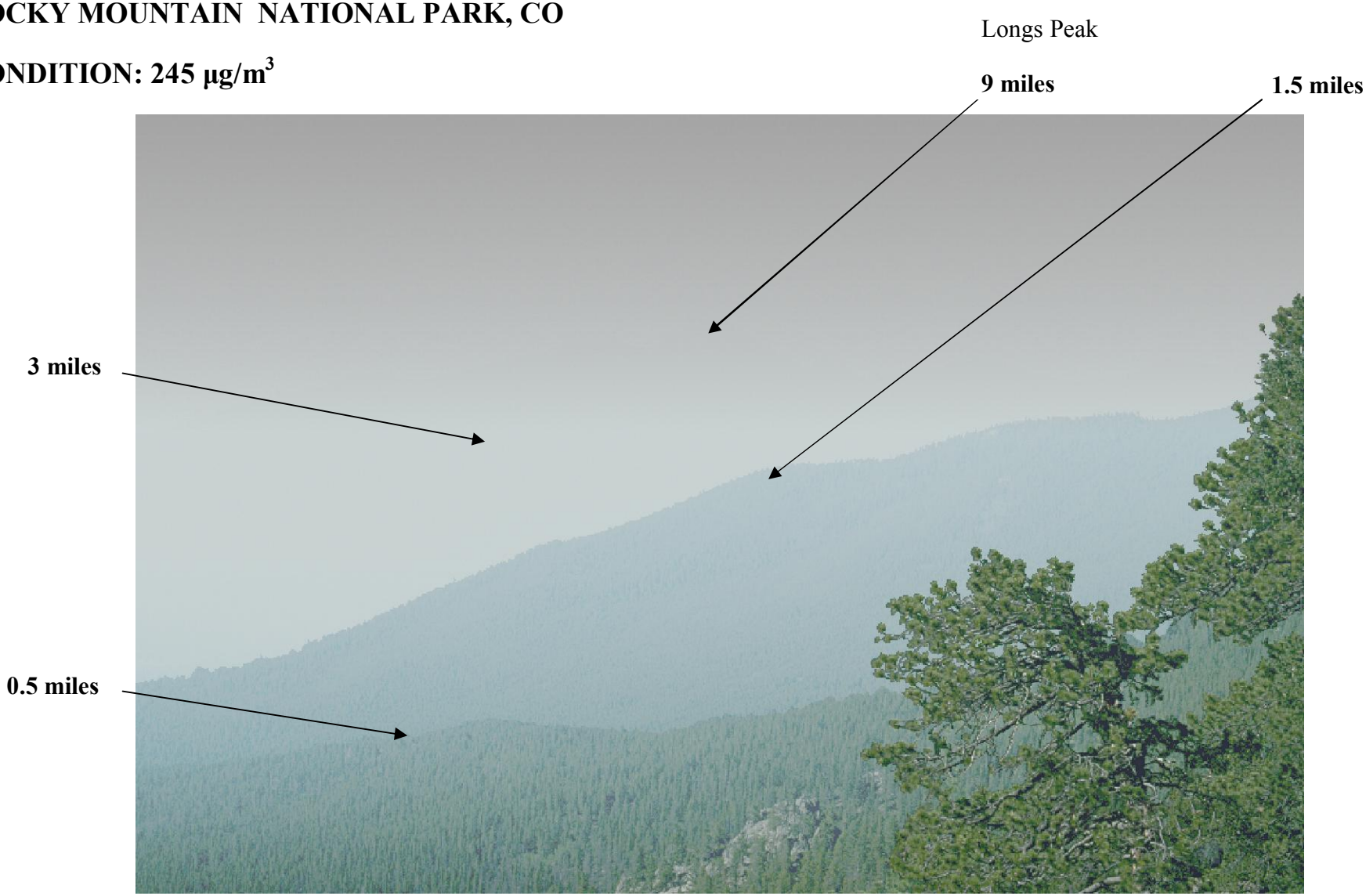
CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**30% - 50%**
Visual Range	**2.3 miles**

ROCKY MOUNTAIN NATIONAL PARK, CO

CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**60% - 70%**
Visual Range	**2.2 miles**

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Air Resources Incorporated. 2013. Resources and Software Downloads. Accessed 28 March 2013. Available at: http://www.air-resource.com/resources/downloads.html.

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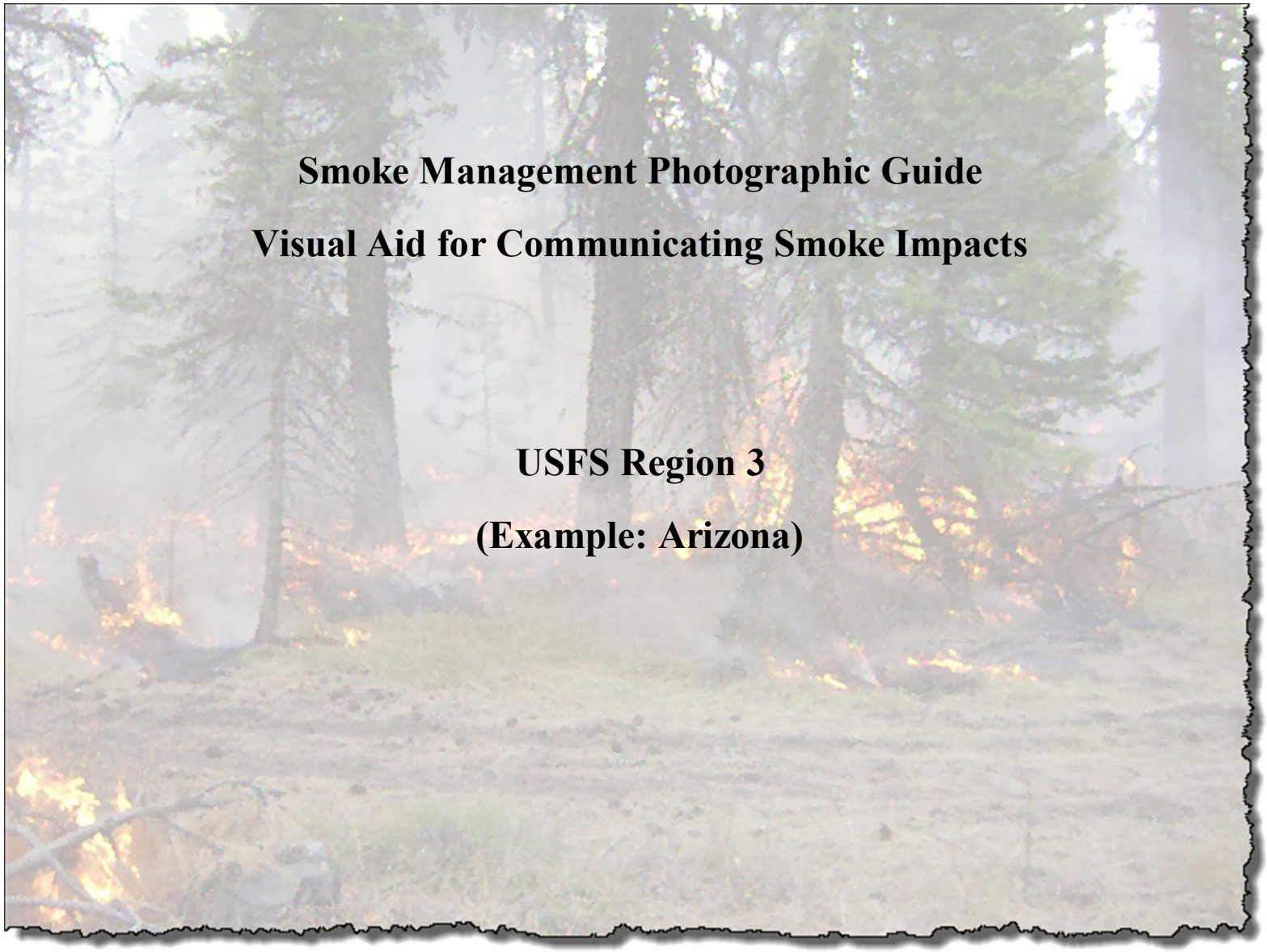


Smoke Management Photographic Guide

Visual Aid for Communicating Smoke Impacts

USFS Region 3

(Example: Arizona)

University of Idaho
College of Natural Resources

Development and Scope:
This guide is developed by the University of Idaho College of Natural Resources with images from US National Park and USDA Forest Service locations.

The primary purpose of this guide is to serve as a tool for communicating potential particulate matter (PM 2.5) levels using visual representation. Numerous factors impact visibility; in addition to particulate matter and the presence of ozone (Aherns 2003), visibility is also affected by compounds including ammonium nitrate, ammonium sulfate, and light absorbing carbon (Malm *et al.* 1994), as well as relative humidity (Achtemeier et al. 2001). Existing background levels of visibility also vary across the country (Core 2001). This guide is intended to indicate smoky conditions in USFS Region 3. Due to the complexity of variables, and limitations in the distances perceived by the human eye, visual approximations should be used as indicators, not precise measurement.

Figure 1 The materials in this guide are for estimation purposes only and indented to represent the overall conditions in the highlighted regions.

Methods
To represent visual impacts from smoke in numerous locations across the Unites States this reference guide has been generated using WinHaze imaging software (Air Resource Specialists Inc. 2013). This software package incorporates several years of particulate data from Class I airsheds throughout the continental United States. The program allows for consistent visual representation of airsheds under varying humidity, background pollutant levels and particulate matter (PM) concentrations based on the IMPROVE equation for estimating ambient light extinction coefficients (Hand and Malm 2006). This methodology facilitates consistent representation of smoky conditions while avoiding variations in sun angle and camera placement that can occur using a more traditional method of matching photographs with monitoring data. Grand Canyon National Park was chosen for this guide based on 857 days of particulate data incorporated into the visual estimates. To establish an image representing the area free of any smoke-impaired visibility a 'baseline' image was generated in WinHaze using the mean values indicated in the table on the left which total less than 5 $\mu g/m^3$ fine particulate matter and less than 5 $\mu g/m^3$ of coarse particulates.

Constituents of PM represented herein ($\mu g/m^3$)		
	Baseline	Elevated
Ammonium Sulfate	0.41	1.59
Ammonium Nitrate	0.1	0.31
Organic Carbon	0.39	-
LAC/Black Carbon	0.11	-
Fine Soil	0.19	1.23
Coarse mass	3.36	7.16

Visual impairment from smoke is simulated first by establishing constant values for the constituent of PM unlikely to change as the result of smoke from fires. 'Elevated' values for ammonium sulfate, ammonium nitrate, fine soil, and coarse mass were determined by using values recorded for the 20% worst visibility days. Organic carbon and Black carbon are then increased to reflect increasing concentrations of smoke, as this carbon

composes nearly 75% of the emissions from forest fires (Andreae & Merlet 2001). The ratio of organic carbon to black carbon will be represented by a 15.4/1 ratio based on estimates for wildland fire in non-tropical forests in a comprehensive review by Andreae & Merlet (2001).

Because relative humidity (RH) impacts visibility and changes throughout the fire season, a range of different RH levels is represented based on morning and afternoon averages. Data for these averages is taken from Flagstaff, AZ (NOAA 2013). Values between the months of May and September were chosen to represent the relative humidity levels most likely to be present during the wildland fire season.

This guide represents short-term (1-3 hour) exposure pollutant levels as presented the Wildfire Smoke, A Guide for Public Health Officials (Lipset *et al.* 2008). The categories ('Good', 'Moderate', etc.) use terminology based on the EPA's Air Quality Index (US EPA, 2009). Due to the difficulty of distinguishing a fine scale measurement such as particulate concentration by using eyesight alone, three values were chosen, each in the mid-range of a health effect index category (*below*).

EPA Values for PM		Concentrations
AQI Value	Actions to protect your health from particle pollution	PM2.5 or PM10 Levels ($\mu g/m^3$) 1 to 3 hour average
Good (0-50)	None	0-38
Moderate (51-100)	Unusually sensitive people should consider reducing prolonged or heavy exertion.	39-88
Unhealthy for Sensitive Groups 101-150	The following groups should reduce prolonged or heavy outdoor exertion: -People with heart or lung disease -Children and older adults Everyone else should limit prolonged or heavy exertion	89-138
Unhealthy (151-200)	The following groups should avoid all physical outdoors: -People with heart or lung disease -Children and older adults Everyone else should avoid prolonged or heavy exertion	139-351
Very Unhealthy (201-300)	The following groups should remain indoors and keep activity levels low: -People with heart or lung disease -Children and older adults Everyone else should avoid all physical activity outdoors	352-526+

19 $\mu g/m^3$

114 $\mu g/m^3$

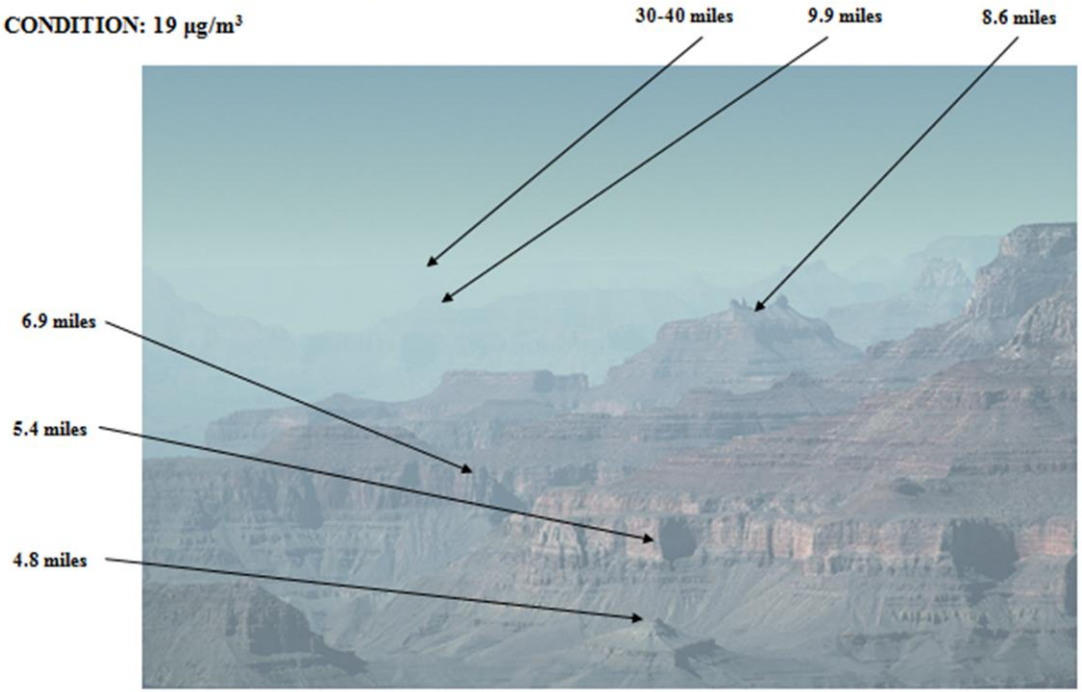
245 $\mu g/m^3$

Using this guide:

To use this guide to represent particulate matter, compare your line of site with landmarks similar distances as those depicted here-in. When making this comparison, face away from the sun. Use points on the landscape of known distances that you are familiar with. Several examples of the same concentration are represented with varying relative humilities based on what is likely to be encountered during the fire season.

GRAND CANYON NATIONAL PARK, AZ

CONDITION: 19 µg/m³

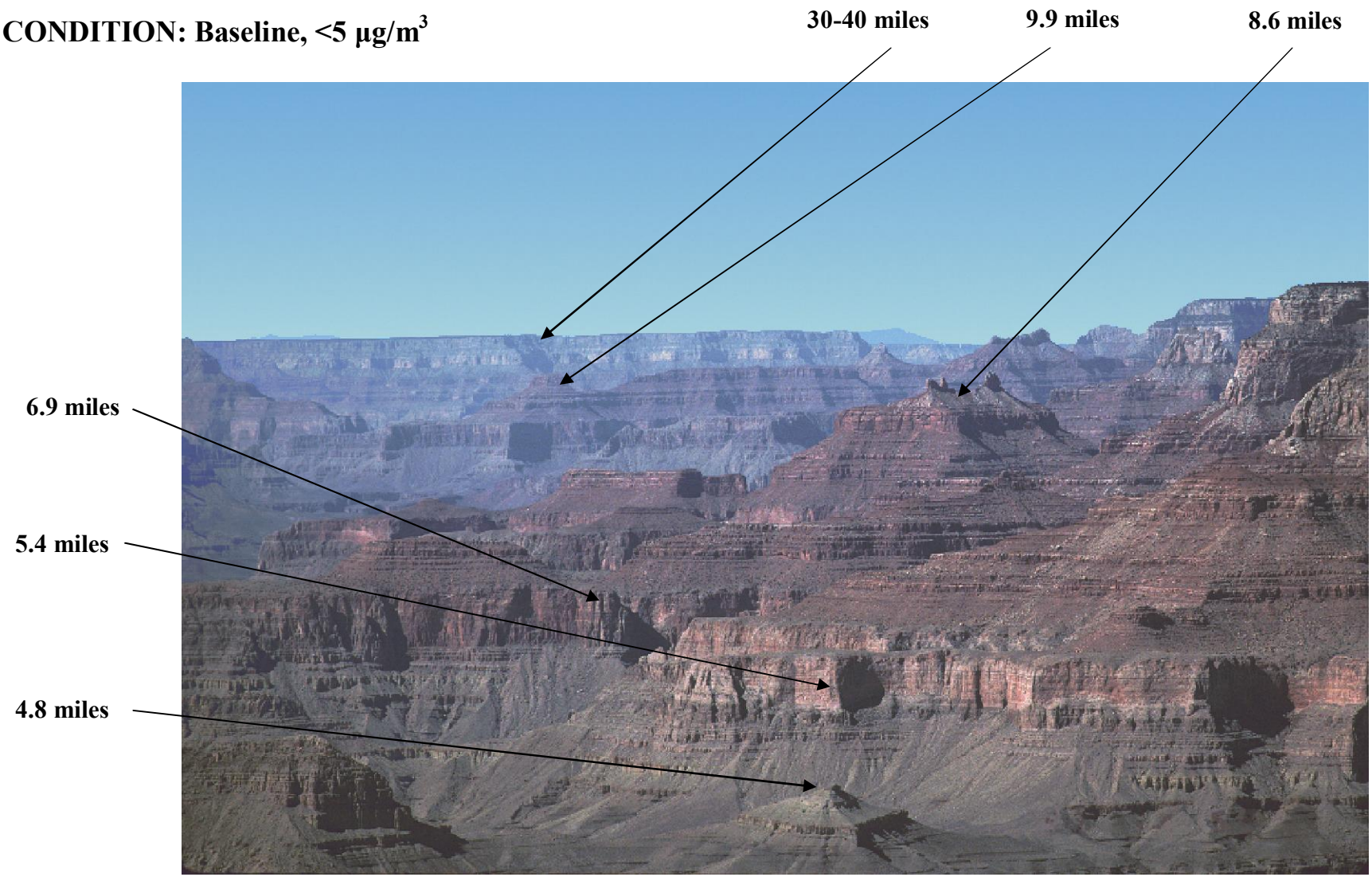


PM2.5	19 µg/m³
Relative Humidity	20% - 30%
Visual Range	26.8 miles

6

GRAND CANYON NATIONAL PARK, AZ

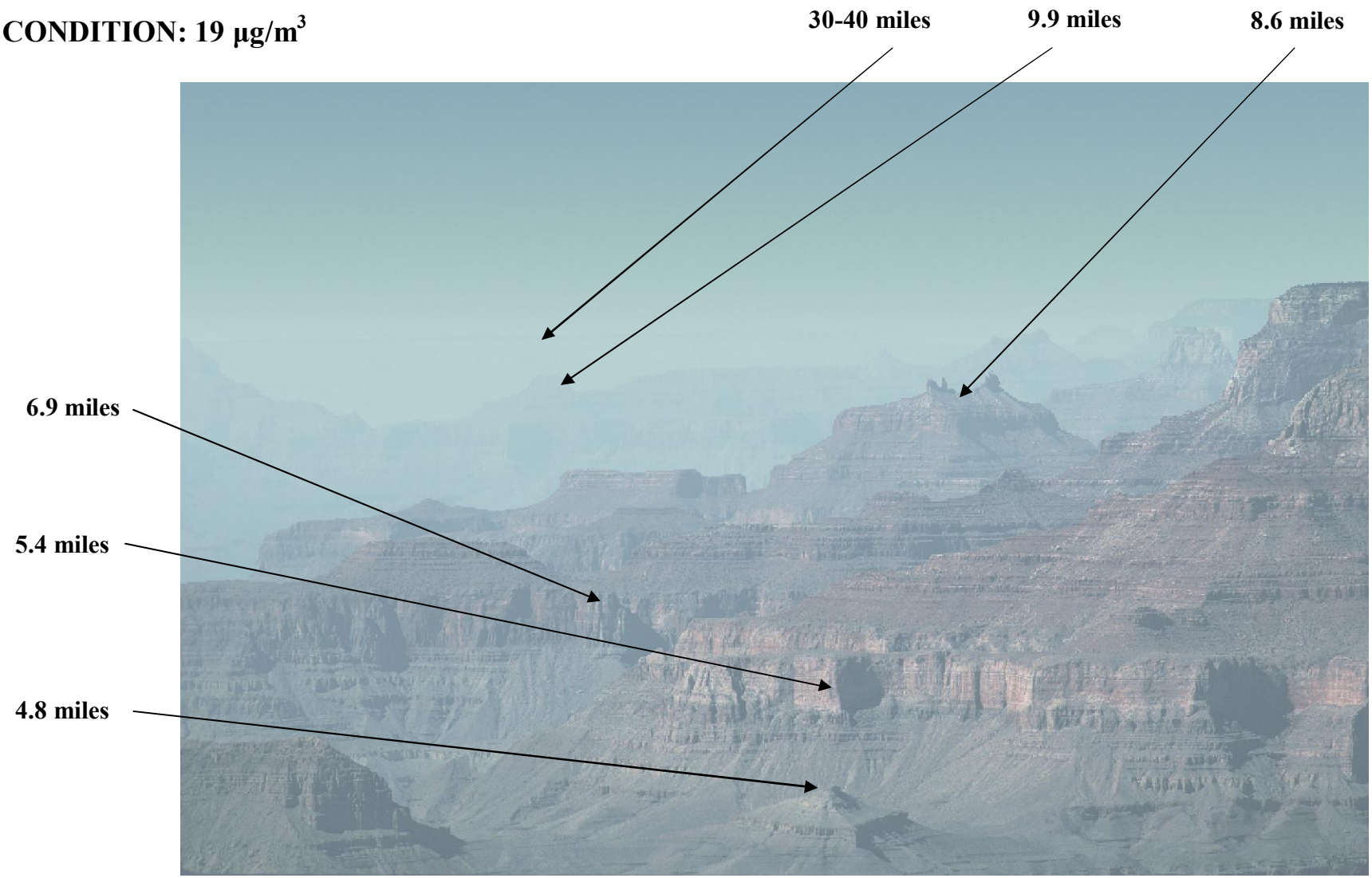
CONDITION: Baseline, <5 µg/m^3



PM 2.5	**<5 µg/m^3**
Relative Humidity	**20 %**
Visual Range	**148.5 miles**

GRAND CANYON NATIONAL PARK, AZ

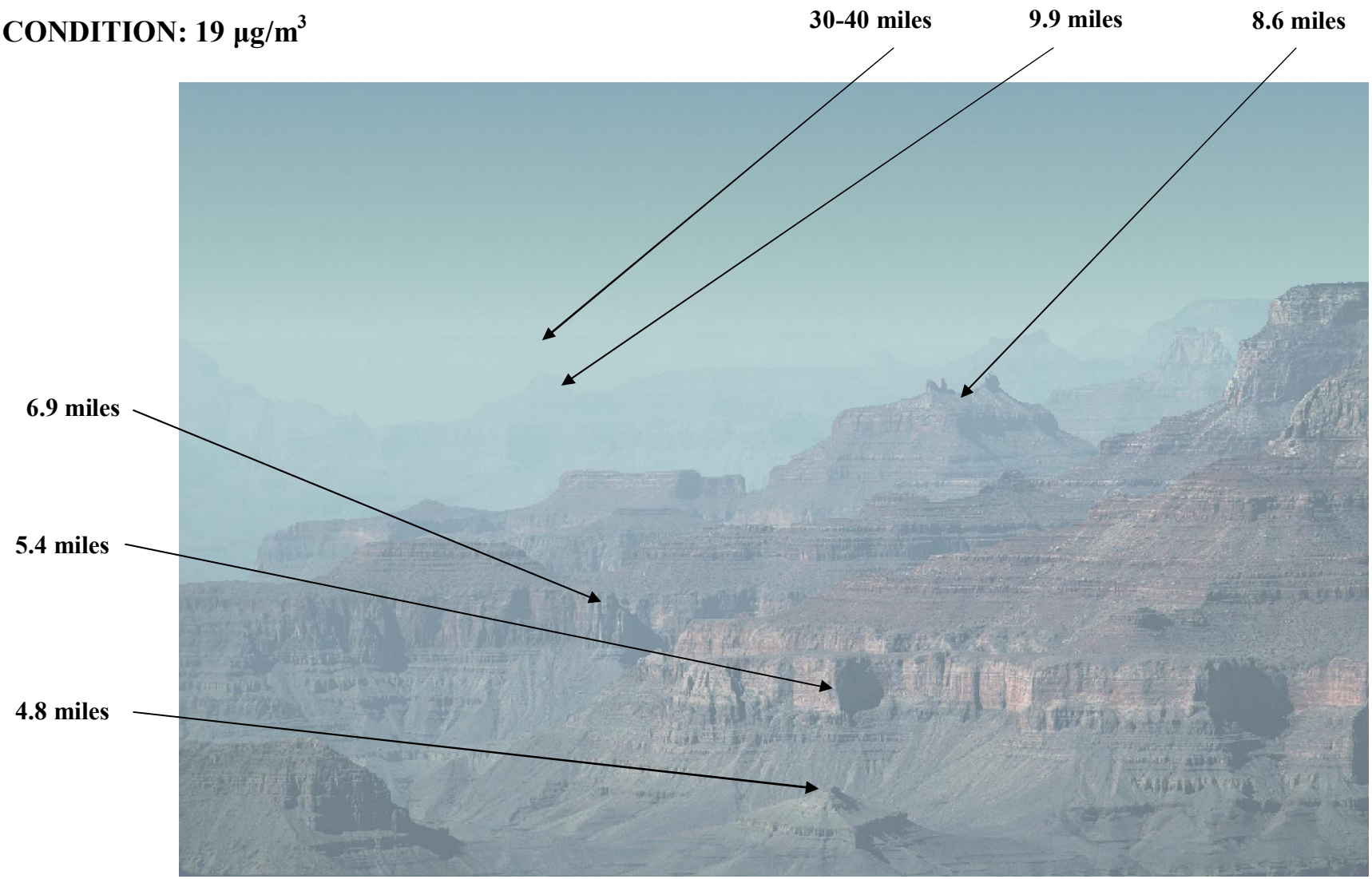
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**20% - 30%**
Visual Range	**26.8 miles**

GRAND CANYON NATIONAL PARK, AZ

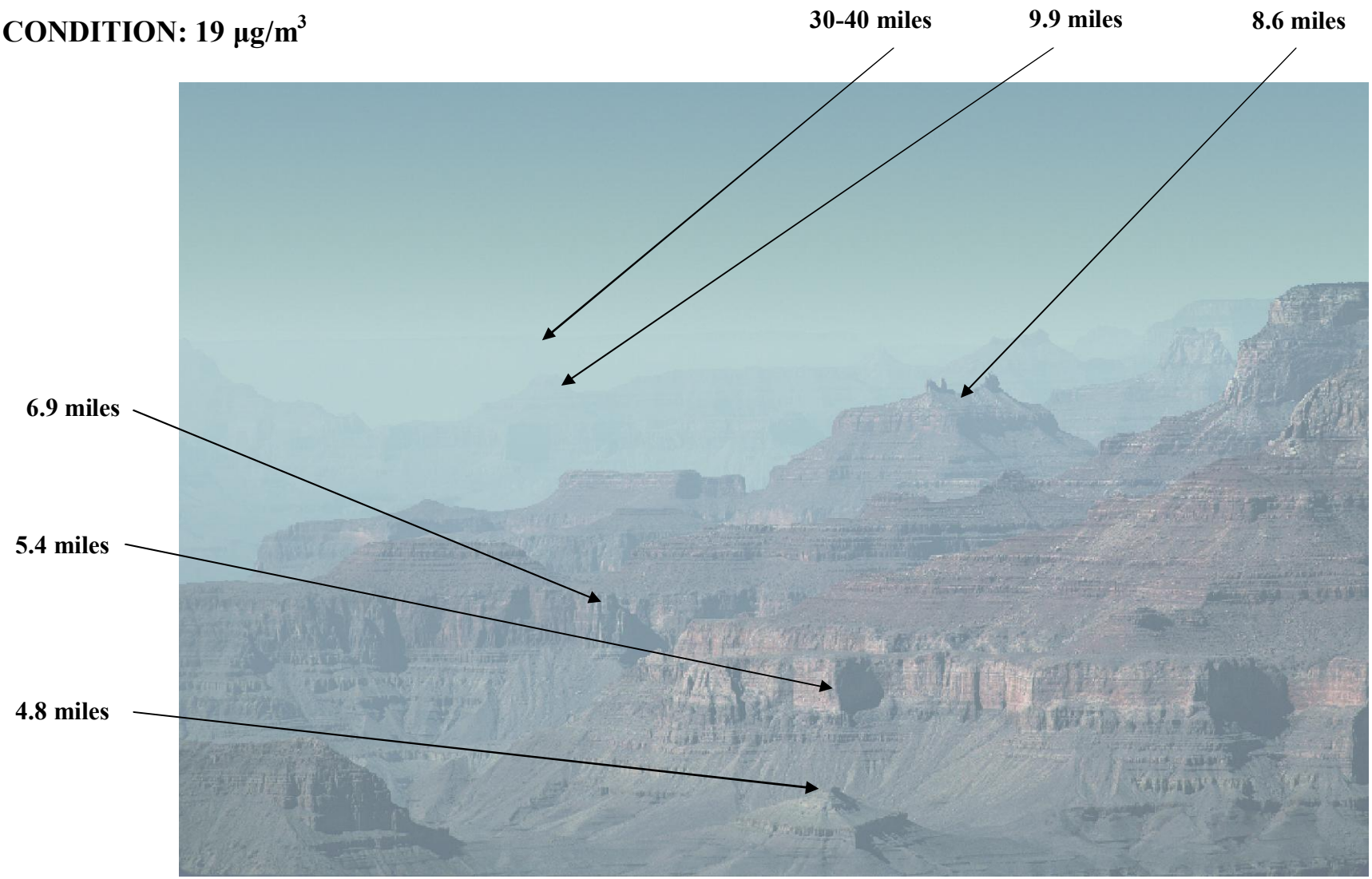
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**40 %**
Visual Range	**26.7 miles**

GRAND CANYON NATIONAL PARK, AZ

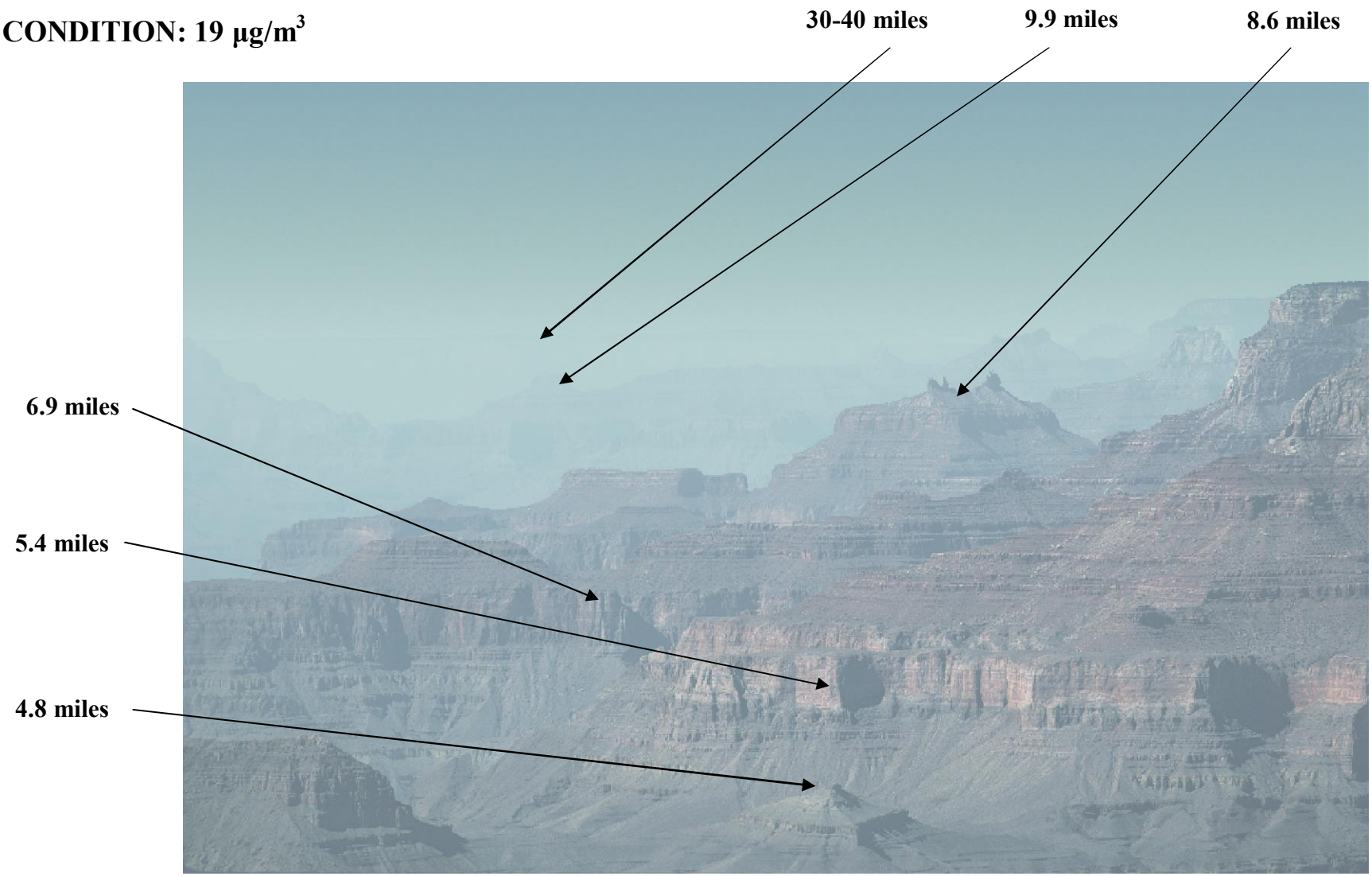
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**50 %**
Visual Range	**26.3 miles**

GRAND CANYON NATIONAL PARK, AZ

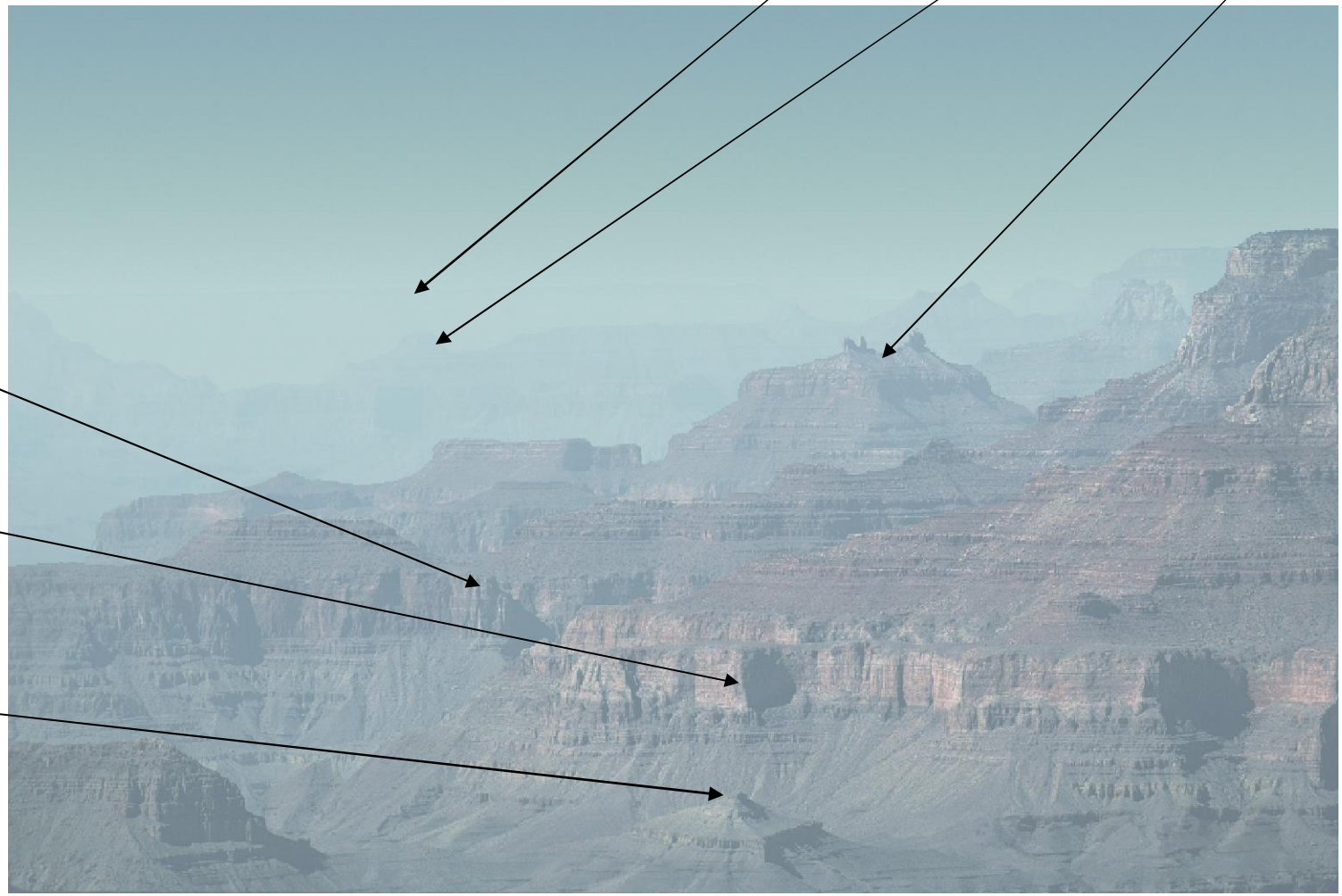
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**60 %**
Visual Range	**25.8 miles**

GRAND CANYON NATIONAL PARK, AZ

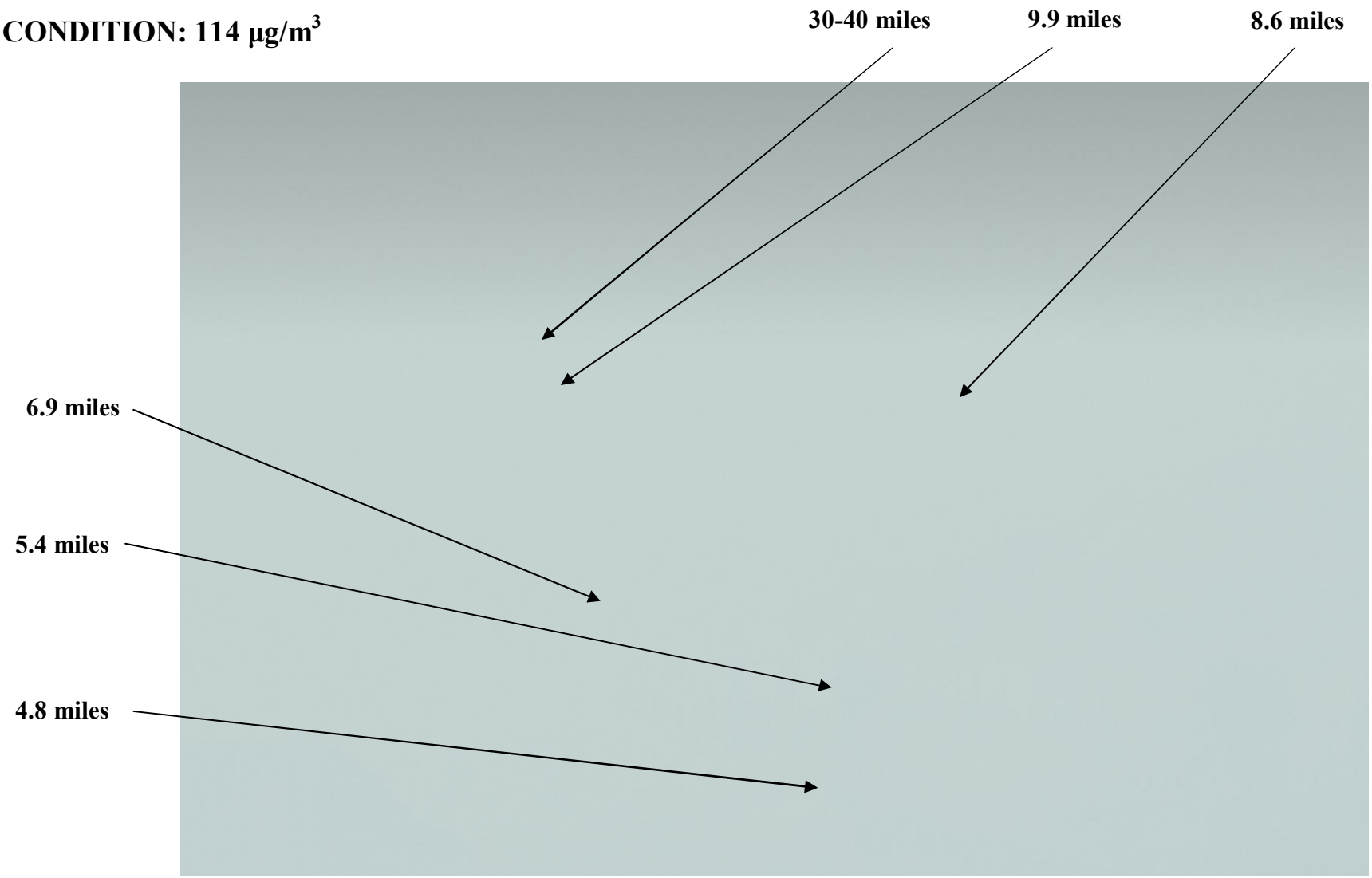
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**70 %**
Visual Range	**25.1 miles**

GRAND CANYON NATIONAL PARK, AZ

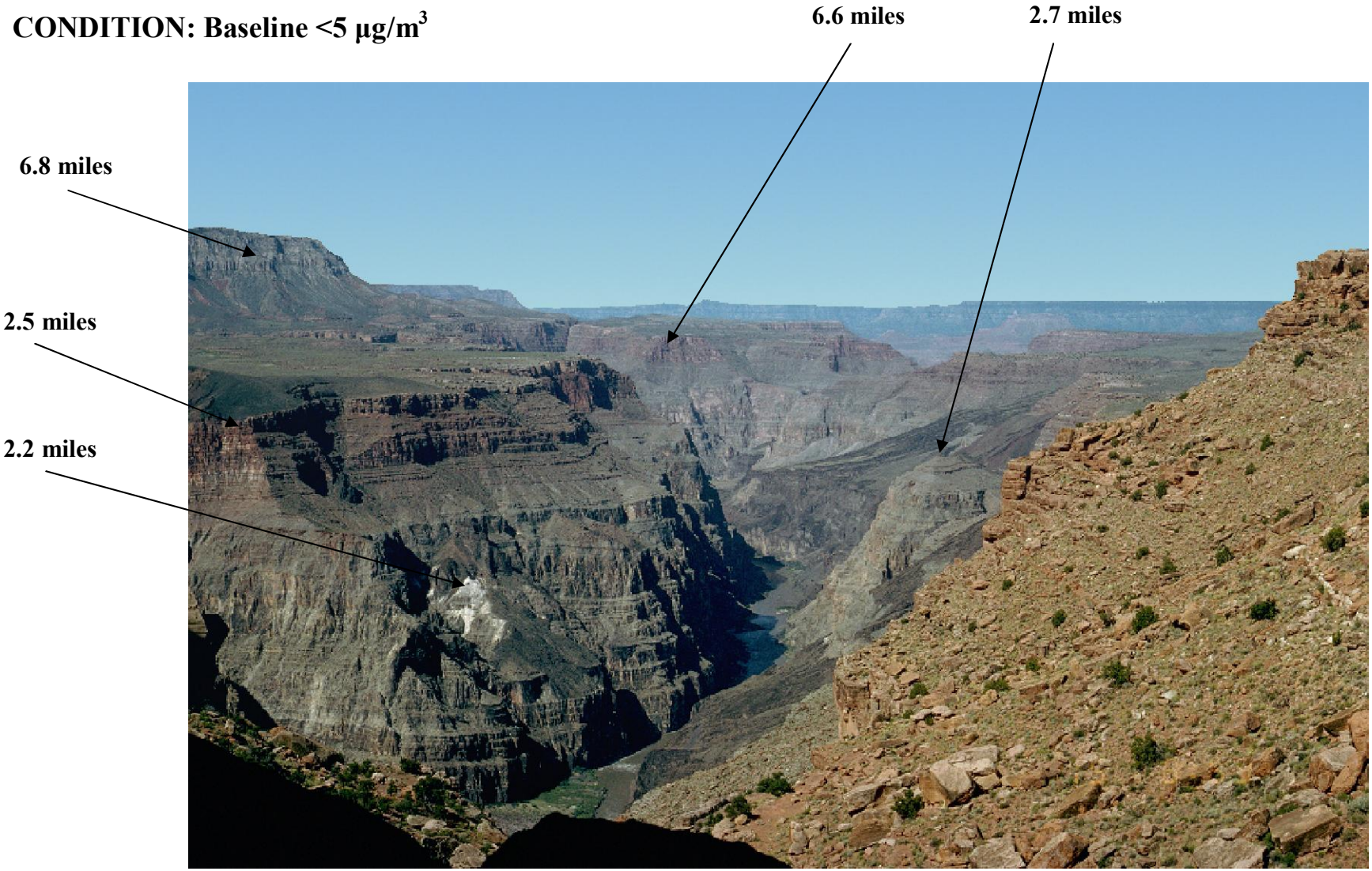
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**20% or more**
Visual Range	**4.8 miles or less**

GRAND CANYON NATIONAL PARK, AZ

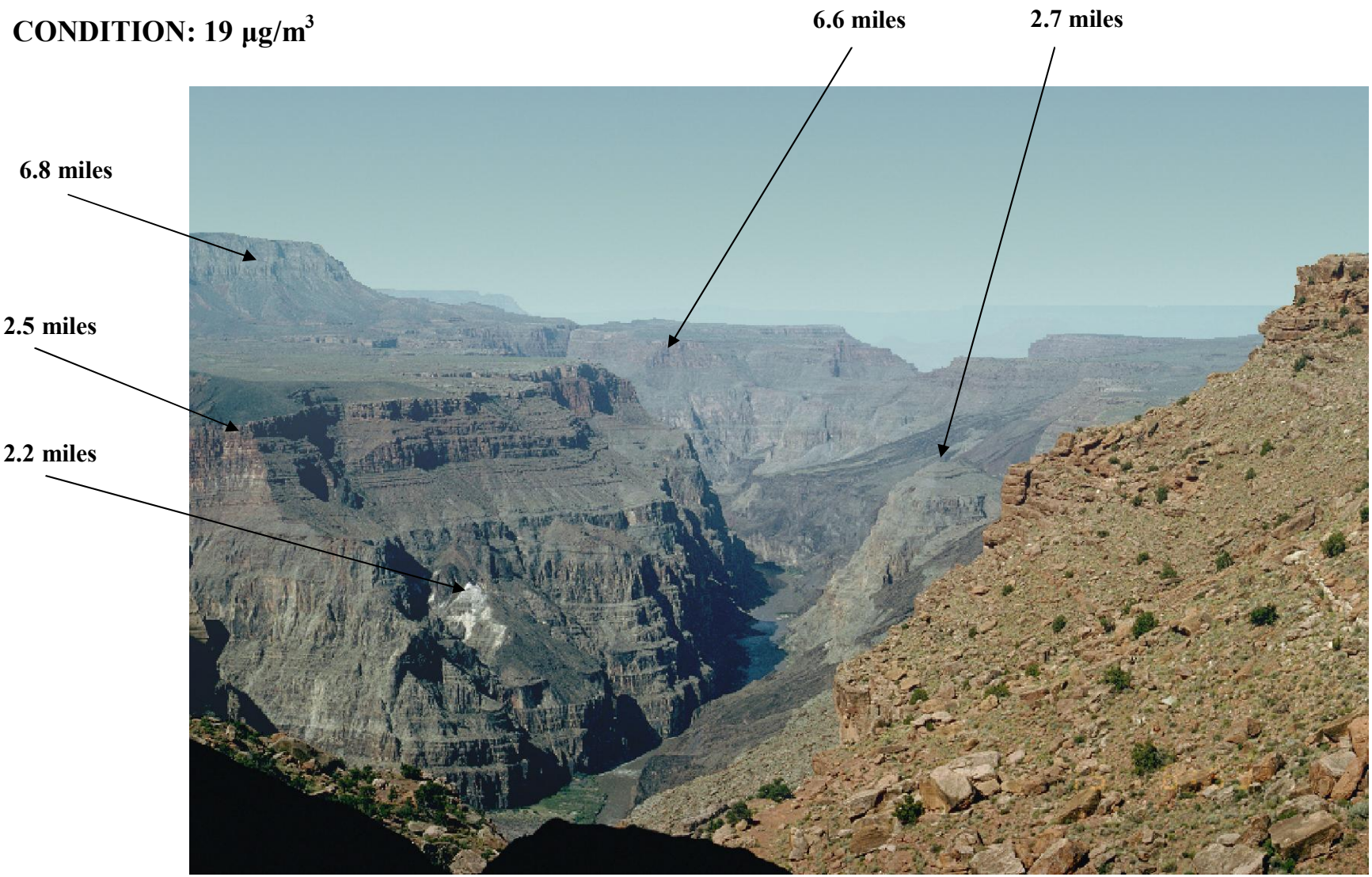
CONDITION: Baseline <5 µg/m^3



PM 2.5	**<5 µg/m^3**
Relative Humidity	**20 %**
Visual Range	**148.5 miles**

GRAND CANYON NATIONAL PARK, AZ

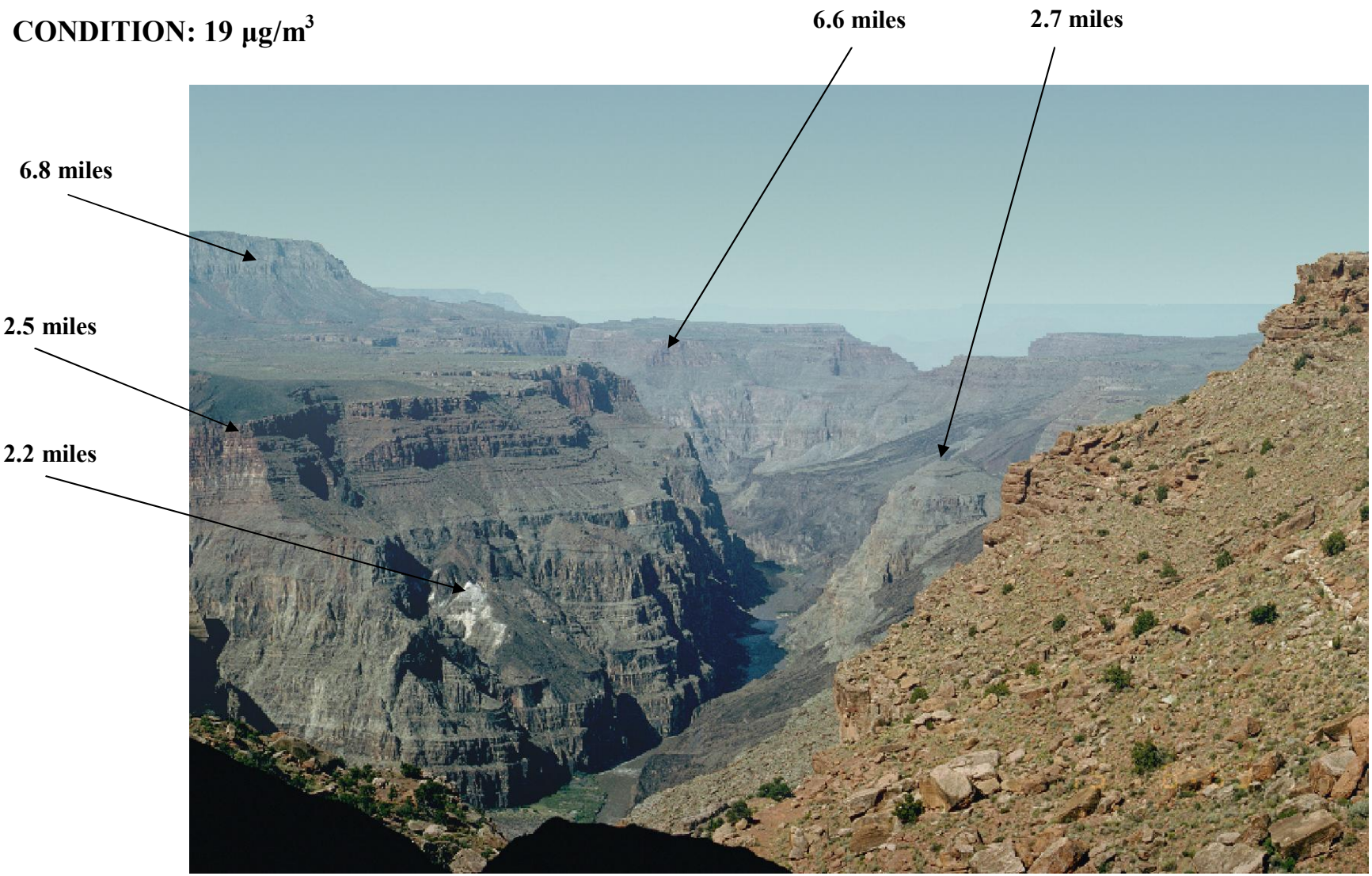
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**20% - 30%**
Visual Range	**26.8 miles**

GRAND CANYON NATIONAL PARK, AZ

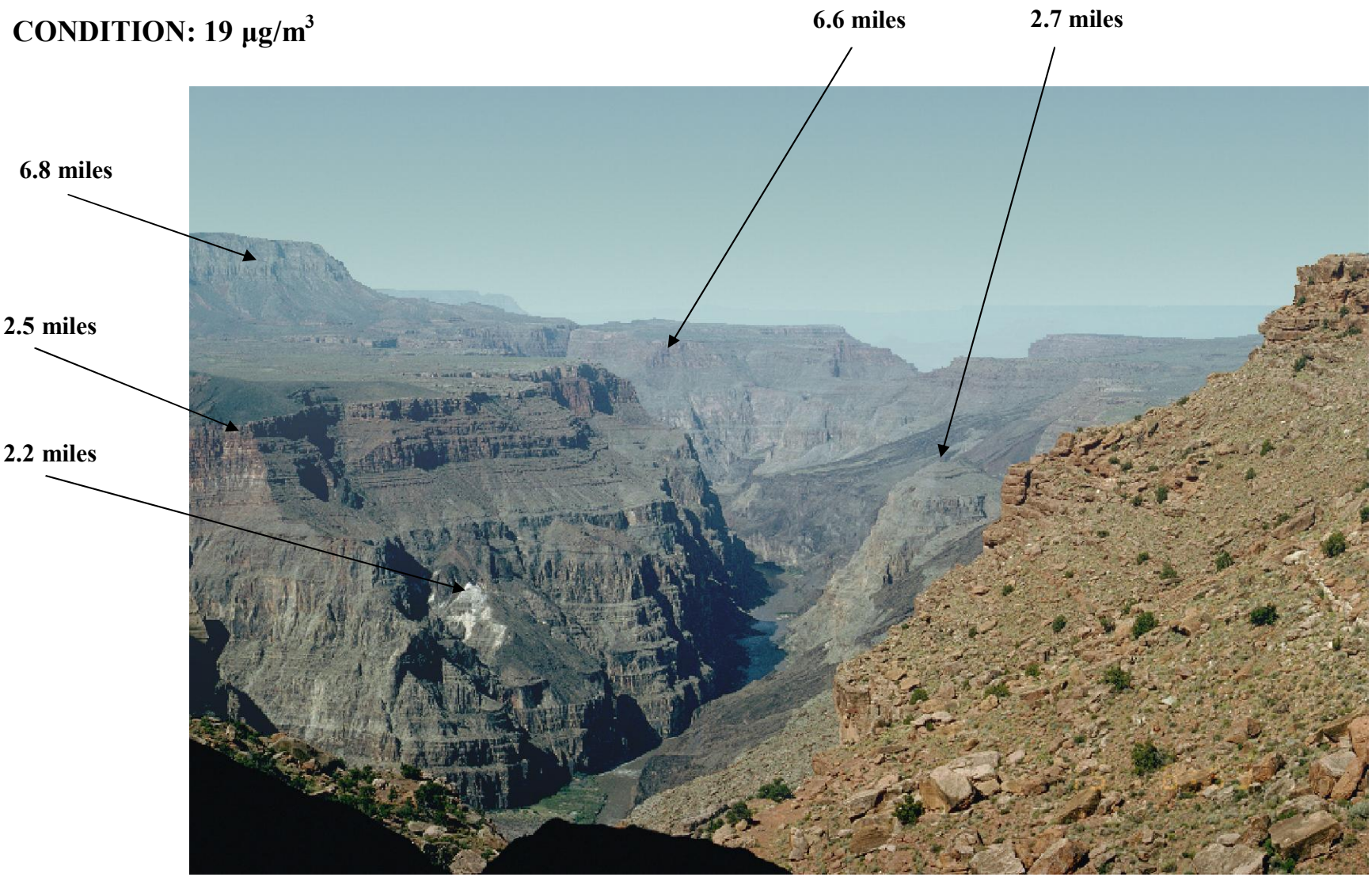
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**40 %**
Visual Range	**26.7 miles**

GRAND CANYON NATIONAL PARK, AZ

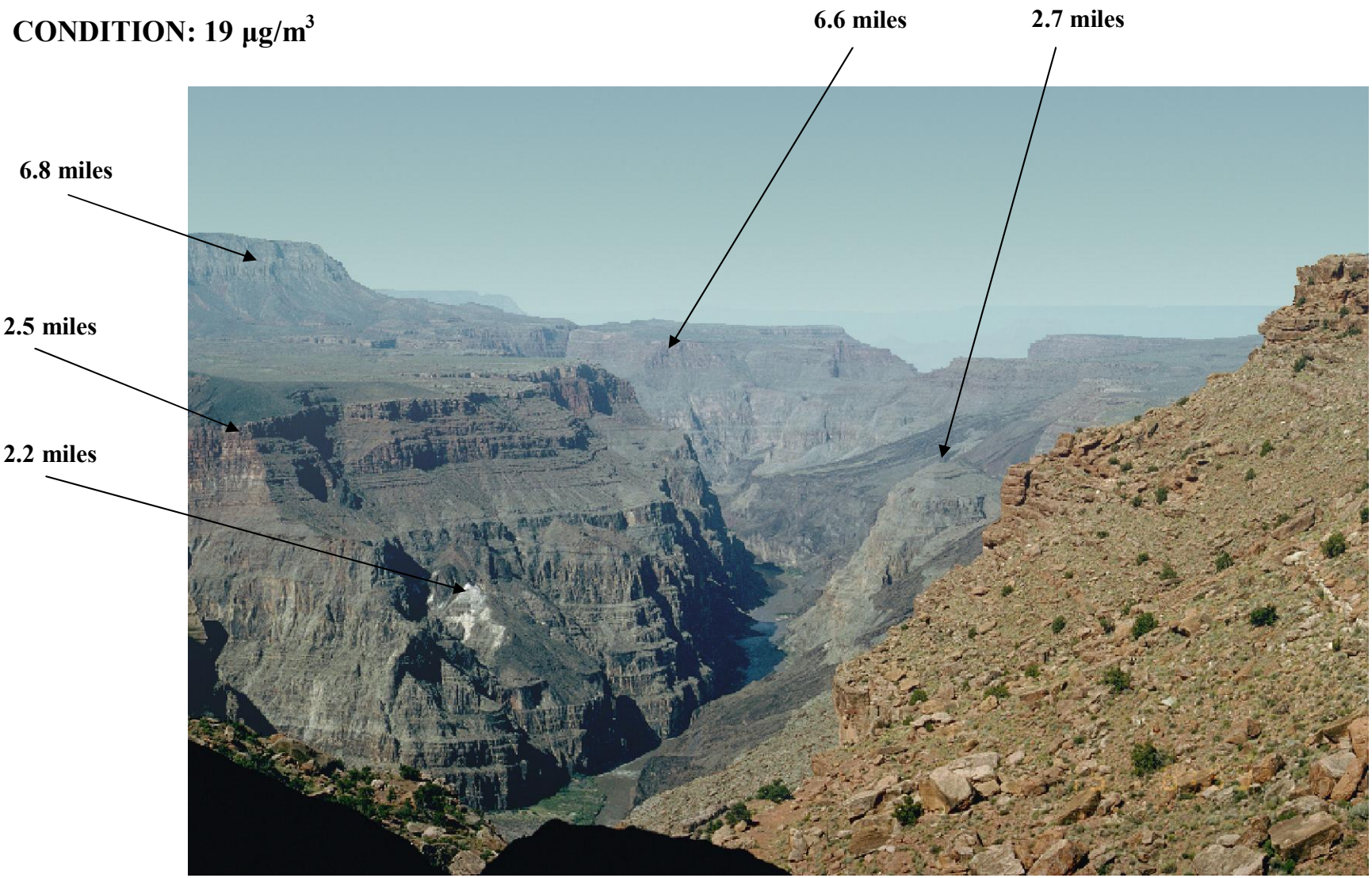
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**50 %**
Visual Range	**26.3 miles**

GRAND CANYON NATIONAL PARK, AZ

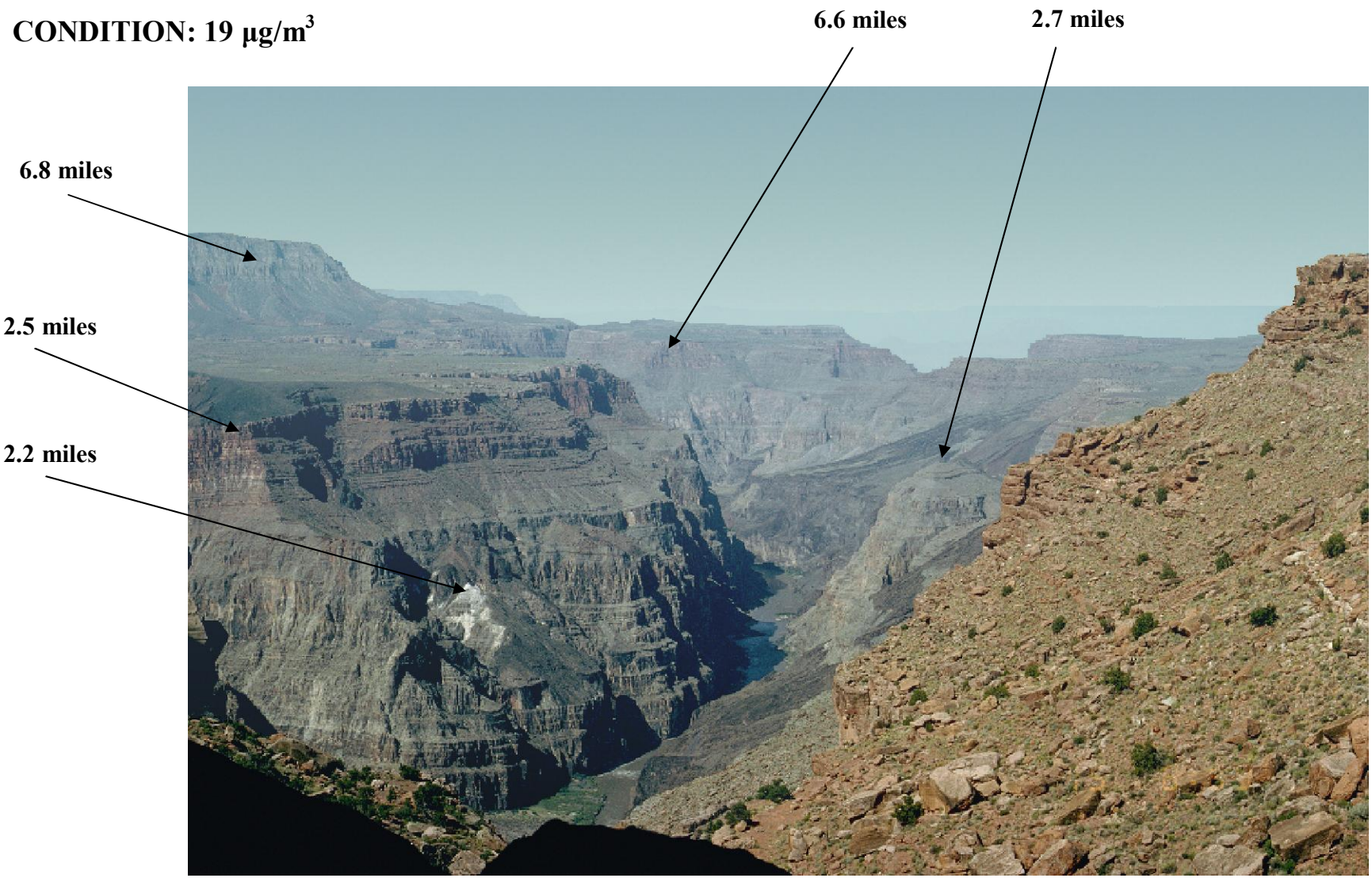
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**60%**
Visual Range	**25.8 miles**

GRAND CANYON NATIONAL PARK, AZ

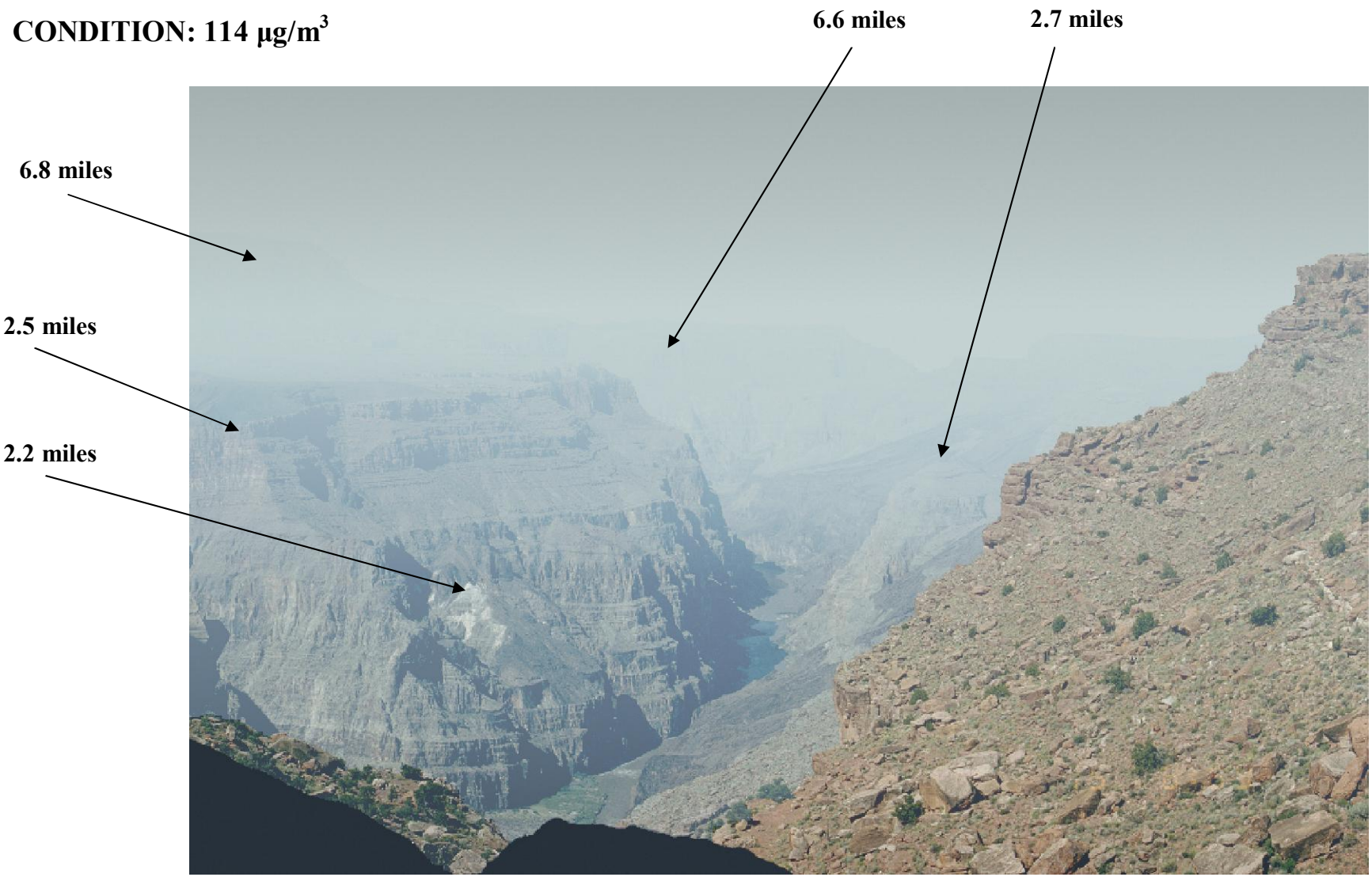
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**70 %**
Visual Range	**25.1 miles**

GRAND CANYON NATIONAL PARK, AZ

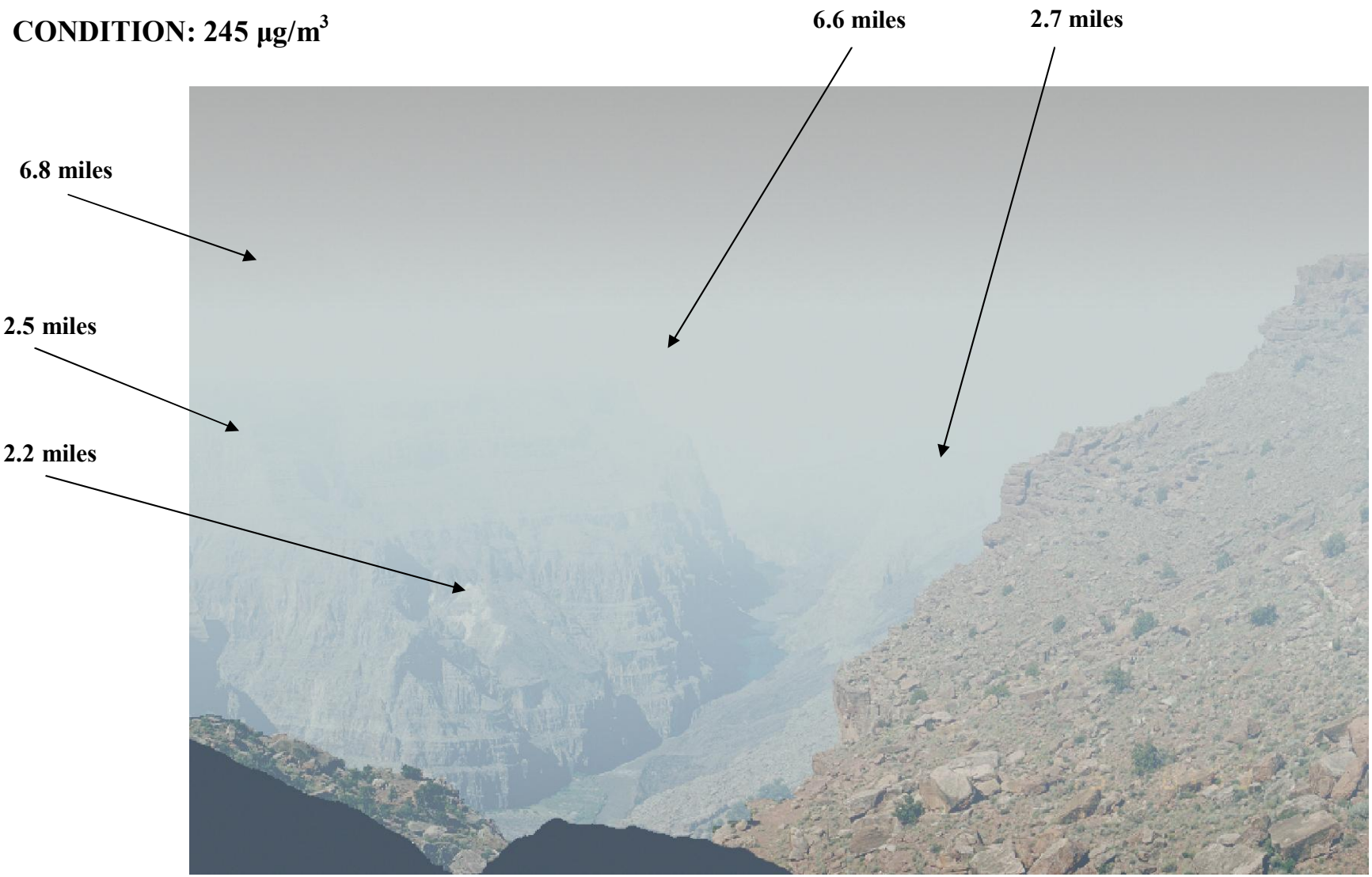
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**20% - 70%**
Visual Range	**4.8 miles**

GRAND CANYON NATIONAL PARK, AZ

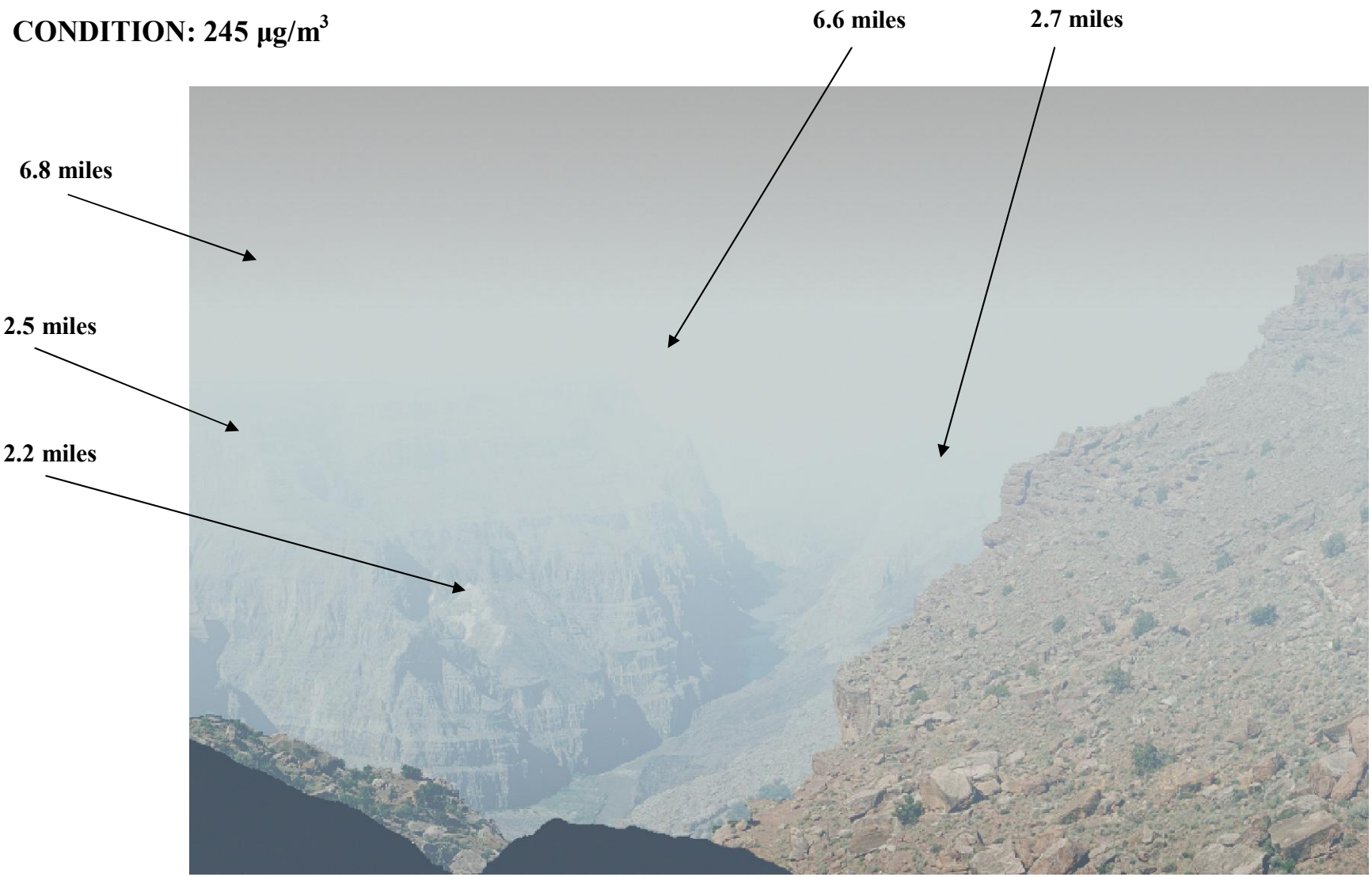
CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**20% - 40%**
Visual Range	**2.3 miles**

GRAND CANYON NATIONAL PARK, AZ

CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**50 % or more**
Visual Range	**2.2 miles of less**

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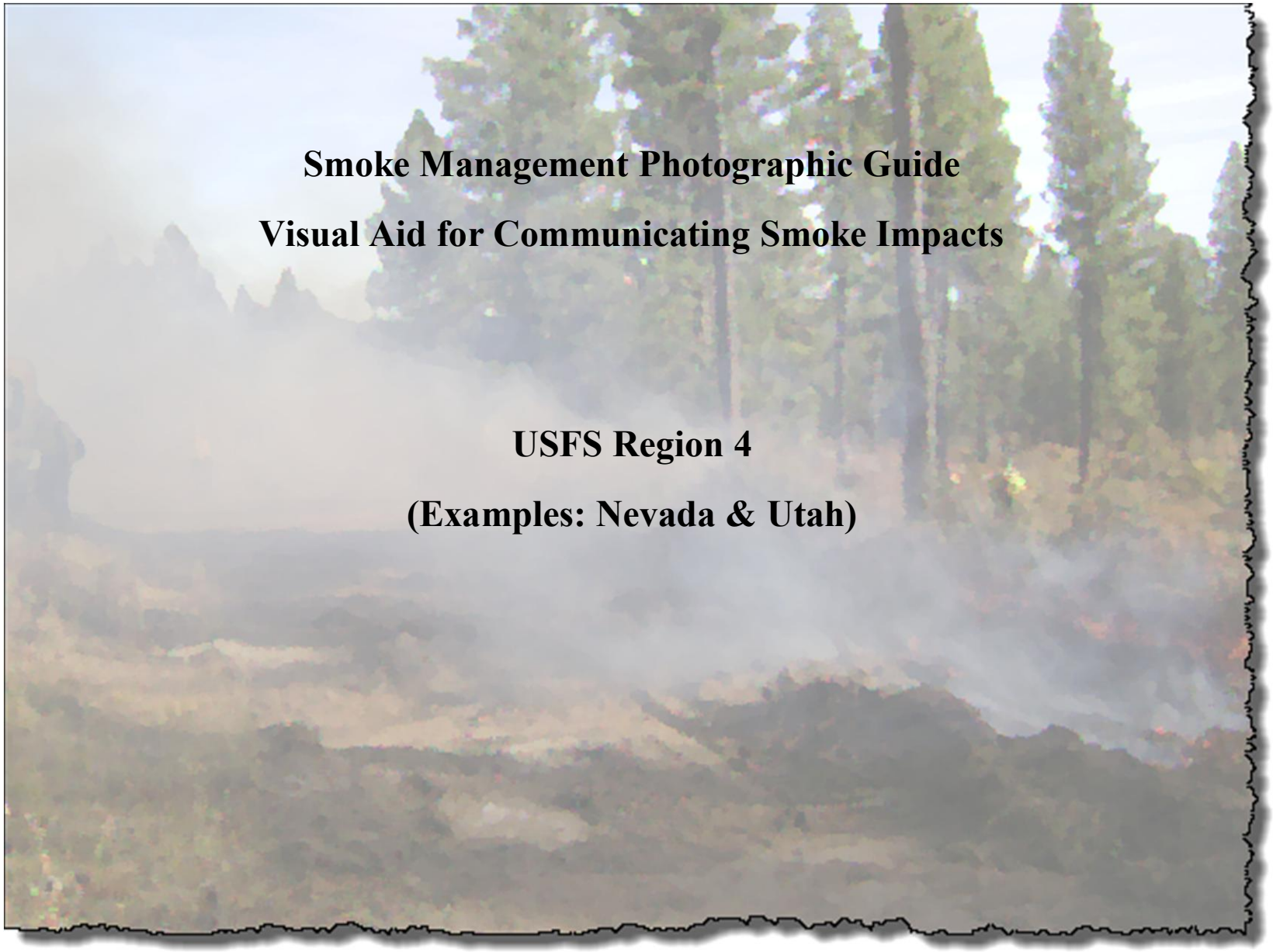

Smoke Management Photographic Guide

Visual Aid for Communicating Smoke Impacts

USFS Region 4

(Examples: Nevada & Utah)

University of Idaho
College of Natural Resources

Figure 1 The materials in this guide are for estimation purposes only and indented to represent the overall conditions in the highlighted regions.

Development and Scope:
This guide is developed by the University of Idaho College of Natural Resources with images from US National Park and USDA Forest Service locations.

The primary purpose of this guide is to serve as a tool for communicating potential particulate matter (PM 2.5) levels using visual representation. Numerous factors impact visibility; in addition to particulate matter and the presence of ozone (Aherns 2003), visibility is also affected by compounds including ammonium nitrate, ammonium sulfate, and light absorbing carbon (Malm *et al.* 1994), as well as relative humidity (Achtemeier et al. 2001). Existing background levels of visibility also vary across the country (Core 2001). This guide is intended to indicate smoky conditions in USFS Region 4. Due to the complexity of variables, and limitations in the distances perceived by the human eye, visual approximations should be used as indicators, not precise measurement.

Methods
To represent visual impacts from smoke in numerous locations across the Unites States this reference guide has been generated using WinHaze imaging software (Air Resource Specialists Inc. 2013). This software package incorporates several years of particulate data from Class I airsheds throughout the continental United States. The program allows for consistent visual representation of airsheds under varying humidity, background pollutant levels and particulate matter (PM) concentrations based on the IMPROVE equation for estimating ambient light extinction coefficients (Hand and Malm 2006). This methodology facilitates consistent representation of smoky conditions while avoiding variations in sun angle and camera placement that can occur using a more traditional method of matching photographs with monitoring data. Great Basin National Park was chosen for this guide based on 681 days of particulate data incorporated into the visual estimates. To establish an image representing the area free of any smoke-impaired visibility a 'baseline' image was generated in WinHaze using the mean values indicated in the table on the left which total less than 5 $\mu g/m^3$ fine particulate matter and less than 5 $\mu g/m^3$ of coarse particulates.

Constituents of PM represented herein ($\mu g/m^3$)		
	Baseline	Elevated
Ammonium Sulfate	0.248	1.126
Ammonium Nitrate	0.056	0.313
Organic Carbon	0.522	1.58
LAC/Black Carbon	0.145	0.235
Fine Soil	0.149	1.39
Coarse mass	2.485	5.496

Visual impairment from smoke is simulated first by establishing constant values for the constituent of PM unlikely to change as the result of smoke from fires. 'Elevated' values for ammonium sulfate, ammonium nitrate, fine soil, and coarse mass were determined by using values recorded for the 20% worst visibility days. Organic carbon and Black carbon are then increased to reflect increasing concentrations of smoke, as this carbon

composes nearly 75% of the emissions from forest fires (Andreae & Merlet 2001). The ratio of organic carbon to black carbon will be represented by a 8.1/1 ratio based on estimates for wildland fire in savannahs and grasslands in a comprehensive review by Andreae & Merlet (2001).

Because relative humidity (RH) impacts visibility and changes throughout the fire season, a range of different RH levels is represented based on morning and afternoon averages. Data for these averages is taken from Elko, NV CA (NOAA 2013). Values between the months of May and September were chosen to represent the relative humidity levels most likely to be present during the wildland fire season.

This guide represents short-term (1-3 hour) exposure pollutant levels as presented the Wildfire Smoke, A Guide for Public Health Officials (Lipset *et al.* 2008). The categories ('Good', 'Moderate', etc.) use terminology based on the EPA's Air Quality Index (US EPA, 2009). Due to the difficulty of distinguishing a fine scale measurement such as particulate concentration by using eyesight alone, three values were chosen, each in the mid-range of a health effect index category (*below*).

EPA Values for PM		Concentrations
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Unhealthy for Sensitive Groups 101-150	The following groups should reduce prolonged or heavy outdoor exertion: -People with heart or lung disease -Children and older adults Everyone else should limit prolonged or heavy exertion	89-138
Unhealthy (151-200)	The following groups should avoid all physical outdoors: -People with heart or lung disease -Children and older adults Everyone else should avoid prolonged or heavy exertion	139-351
Very Unhealthy (201-300)	The following groups should remain indoors and keep activity levels low: -People with heart or lung disease -Children and older adults Everyone else should avoid all physical activity outdoors	352-526+

19 $\mu g/m^3$

114 $\mu g/m^3$

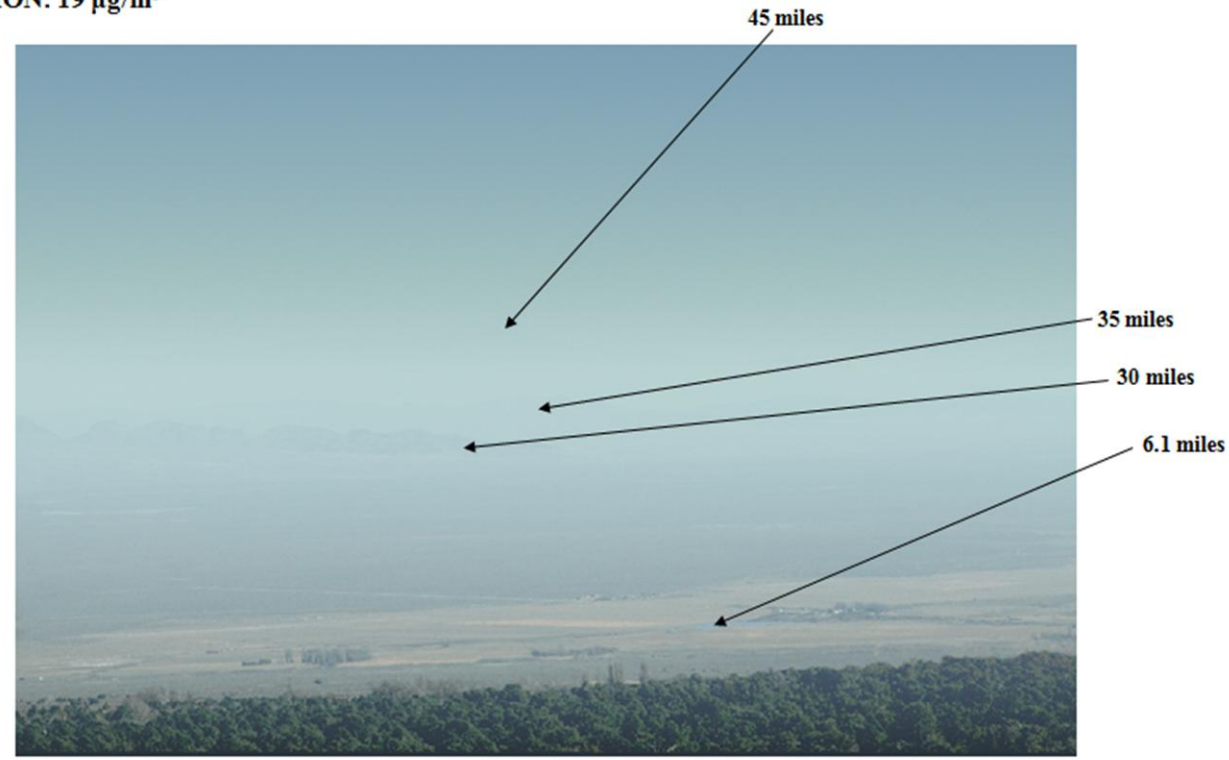
245 $\mu g/m^3$

Using this guide:

To use this guide to represent particulate matter, compare your line of site with landmarks similar distances as those depicted here-in. When making this comparison, face away from the sun. Use points on the landscape of known distances that you are familiar with. Several examples of the same concentration are represented with varying relative humilities based on what is likely to be encountered during the fire season.

GREAT BASIN NATIONAL PARK, NV

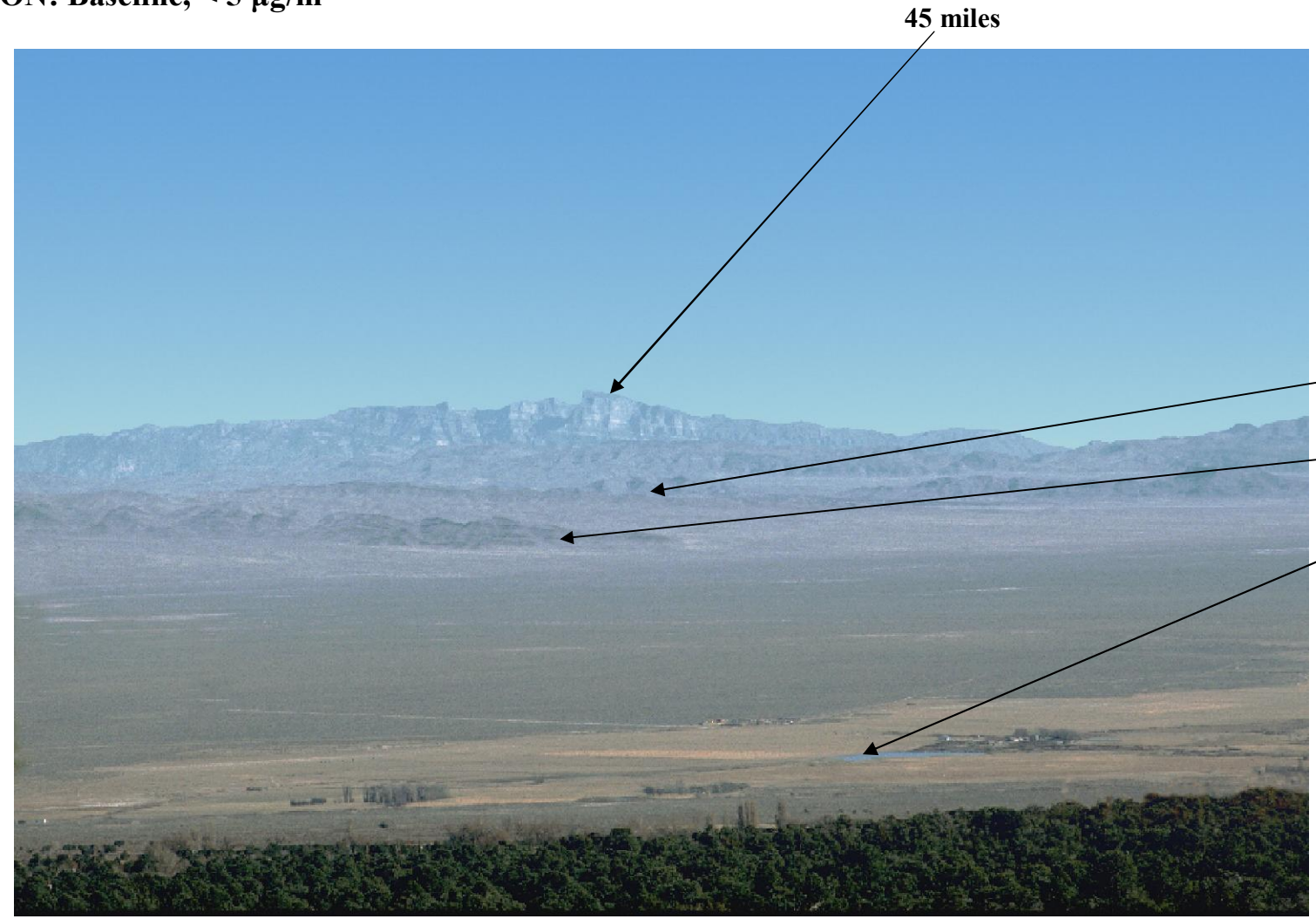
CONDITION: 19 µg/m³



PM 2.5	**19 µg/m³**
Relative Humidity	**20% - 40%**
Visual Range	**25.4 miles**

GREAT BASIN NATIONAL PARK, NV

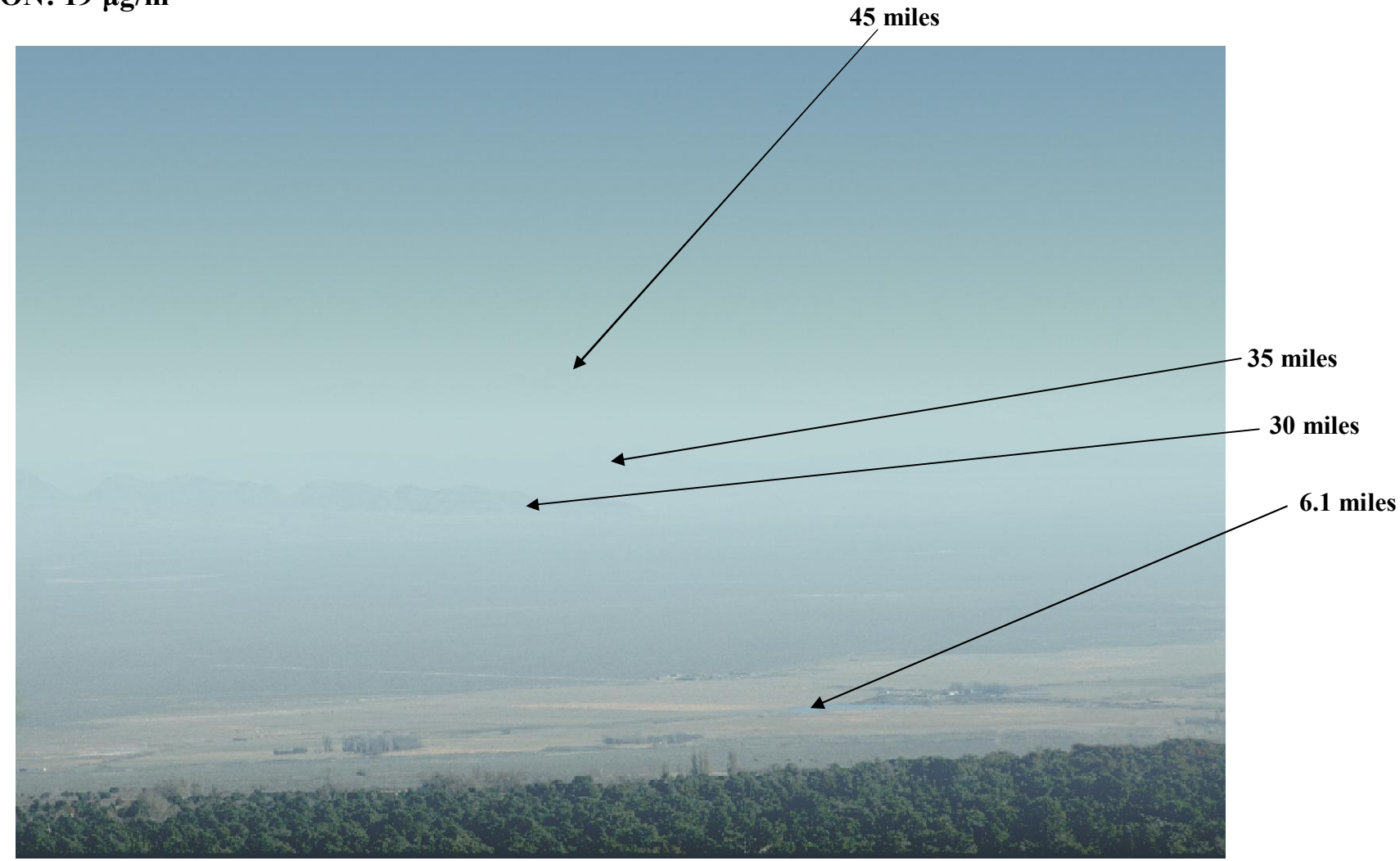
CONDITION: Baseline, < 5 µg/m^3



PM 2.5	**< 5 µg/m^3**
Relative Humidity	**20 %**
Visual Range	**151.03 miles**

GREAT BASIN NATIONAL PARK, NV

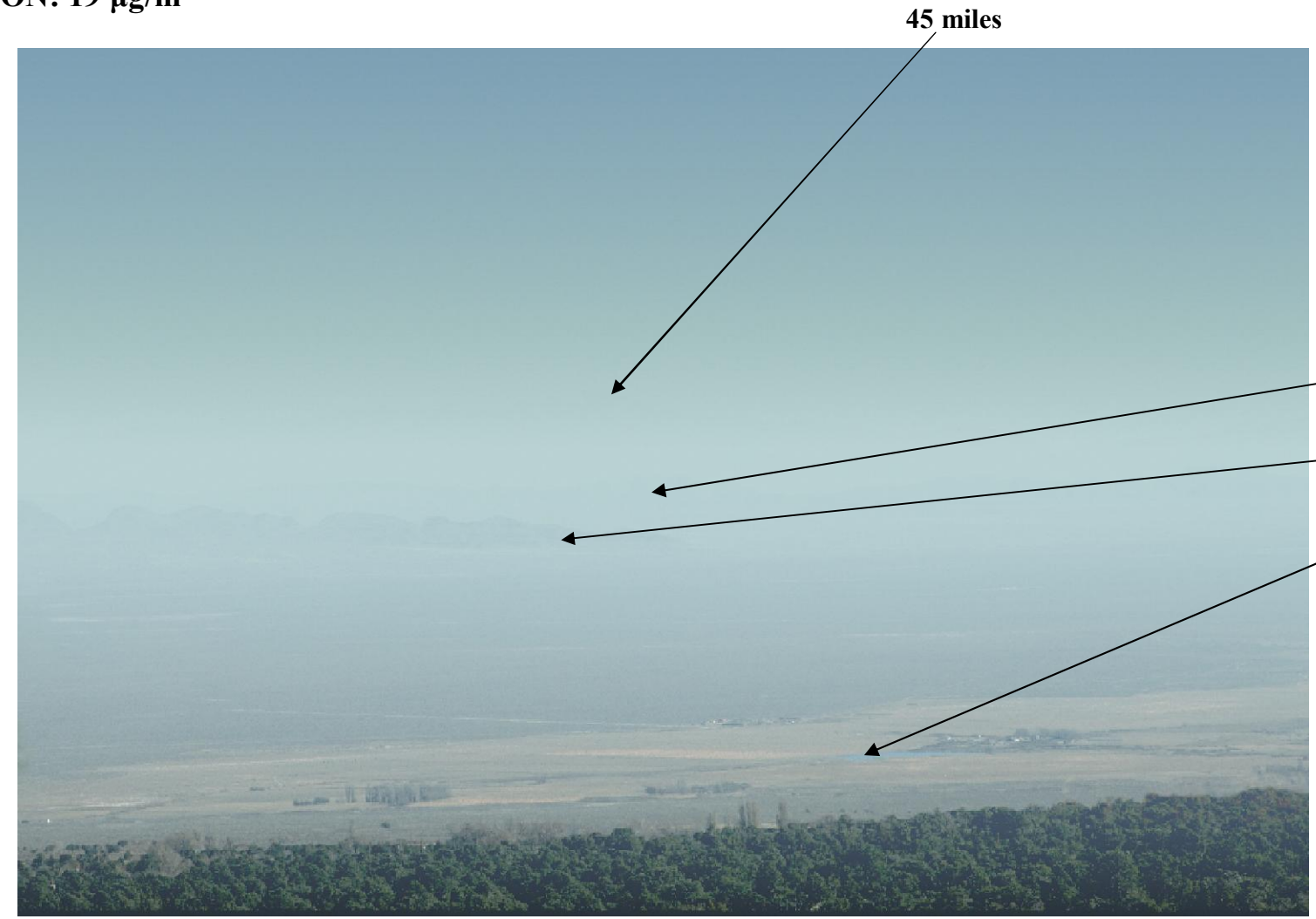
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**20% - 40%**
Visual Range	**25.4 miles**

GREAT BASIN NATIONAL PARK, NV

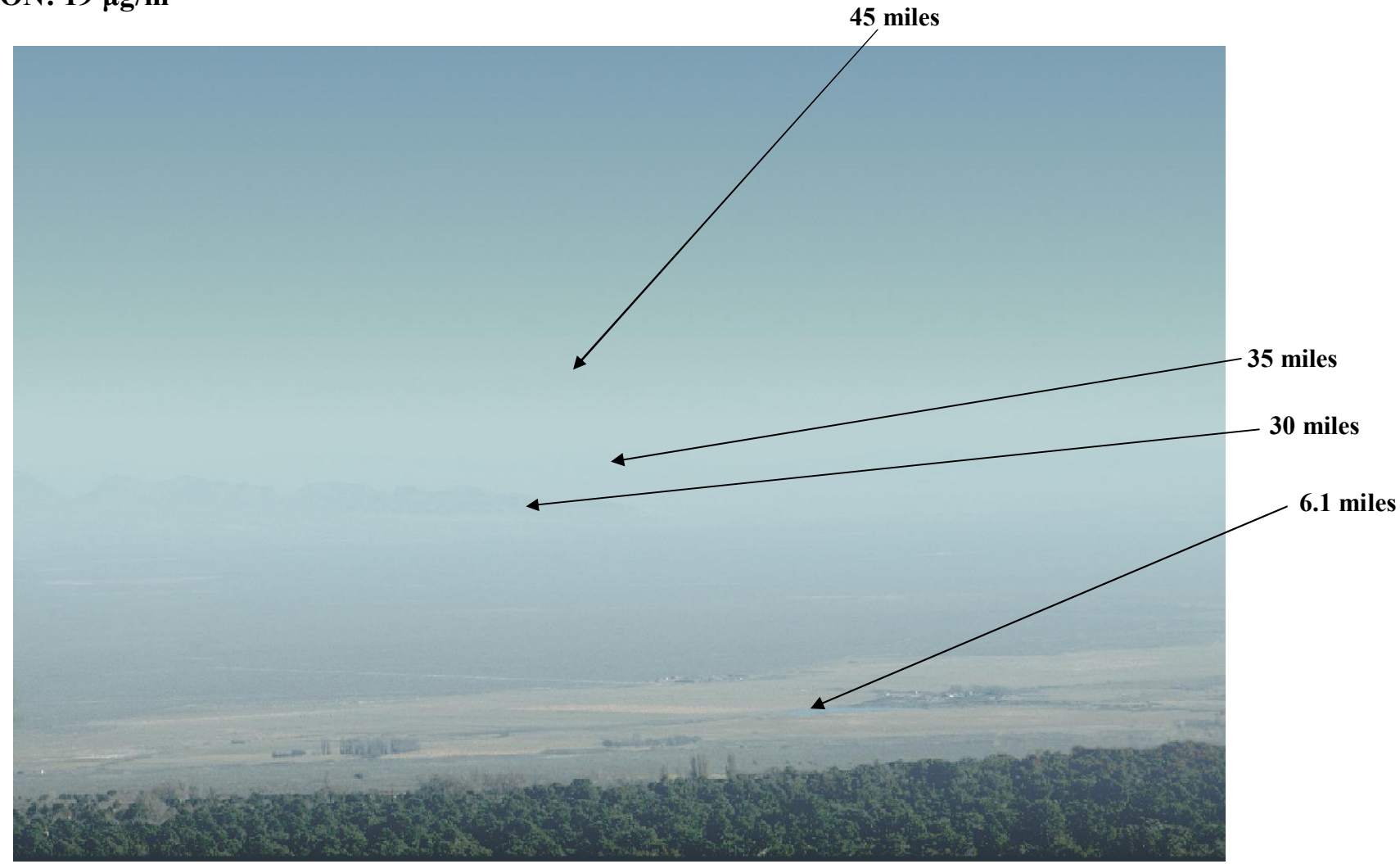
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**50%**
Visual Range	**25.0 miles**

GREAT BASIN NATIONAL PARK, NV

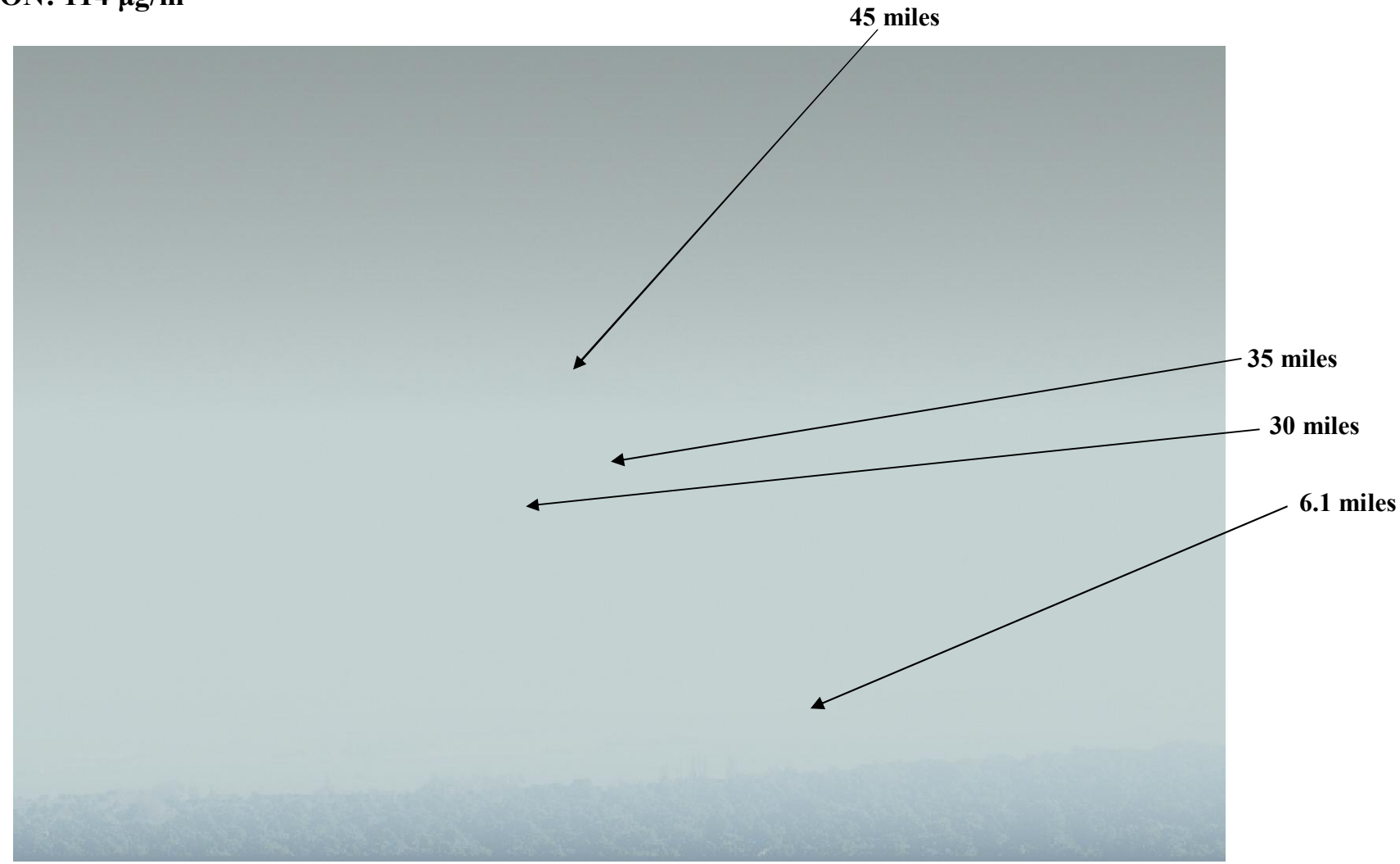
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**60 %**
Visual Range	**24.7 miles**

GREAT BASIN NATIONAL PARK, NV

CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**20% - 60%**
Visual Range	**4.4 miles**

CANYONLANDS NATIONAL PARK, UTAH

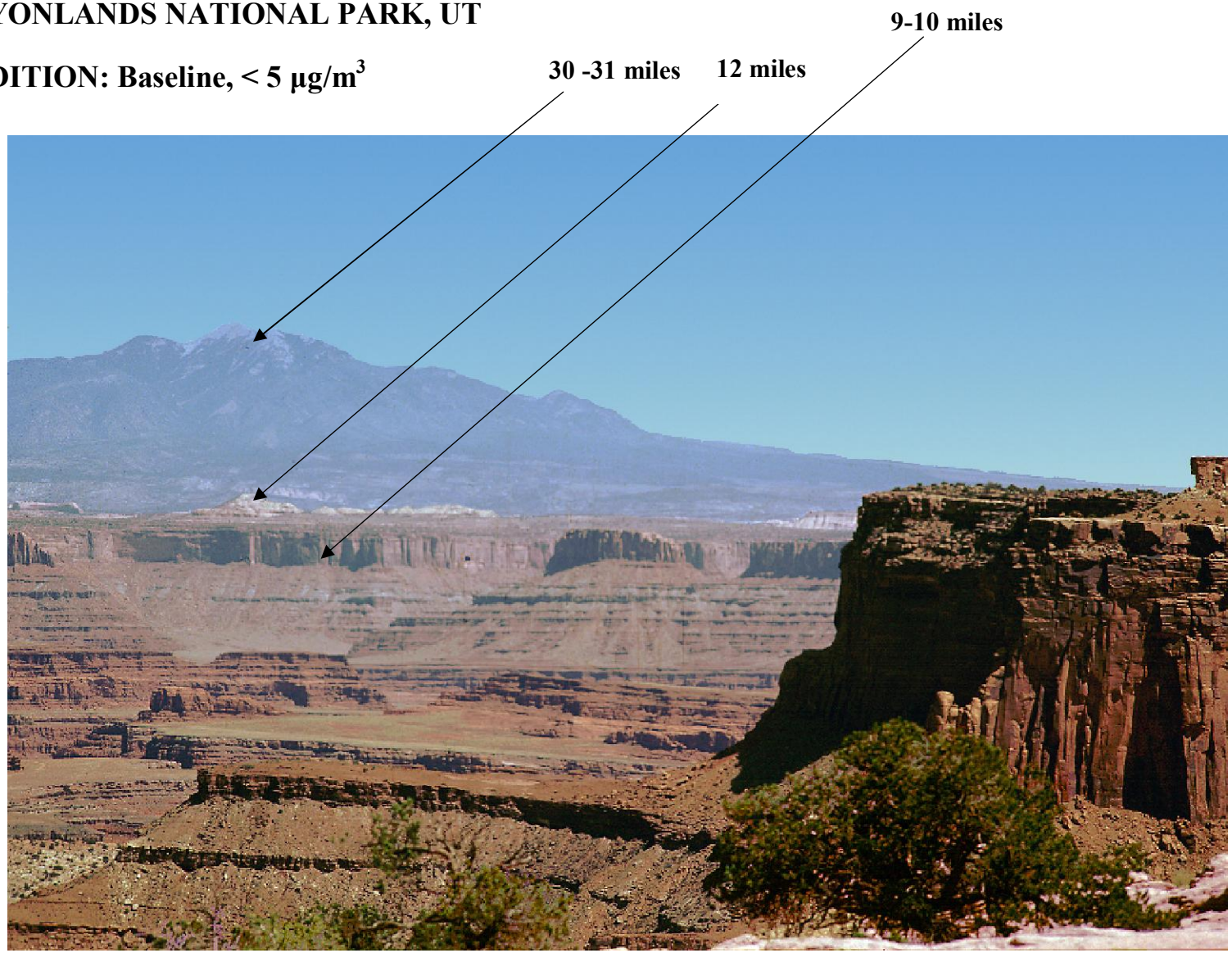
Days of Sampling: 964

Relative Humidity ranging between 20% and 60% taken from Salt Lake City, UT

Constituents of PM represented herein (µg/m^3)		
	Baseline	Elevated
Ammonium Sulfate	0.52	1.54
Ammonium Nitrate	0.13	0.37
Organic Carbon	0.4	-
LAC/Black Carbon	0.11	-
Fine Soil	0.24	1.36
Coarse mass	3.51	8.43

CANYONLANDS NATIONAL PARK, UT

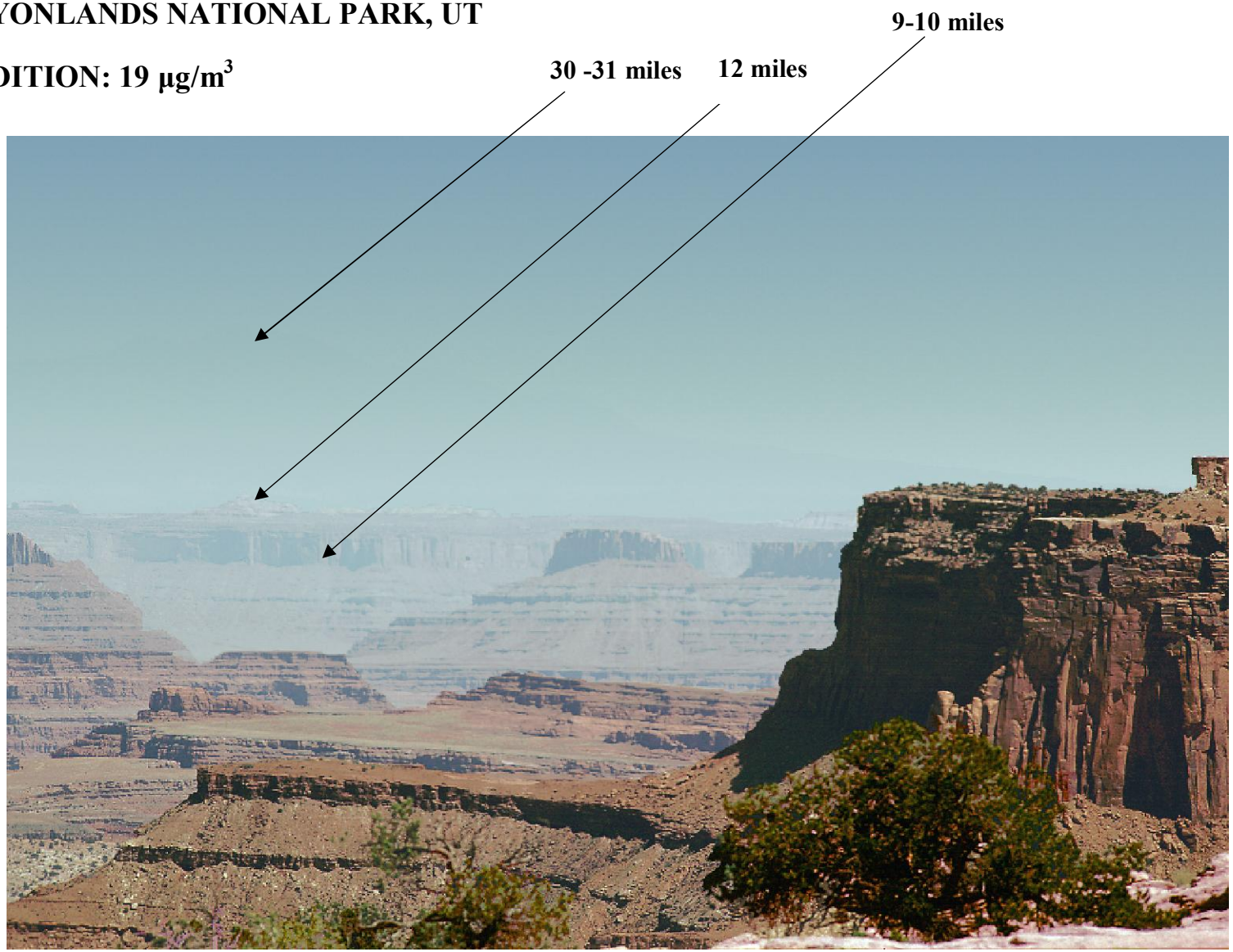
CONDITION: Baseline, < 5 µg/m^3



PM 2.5	**< 5 µg/m^3**
Relative Humidity	**20 %**
Visual Range	**142.9 miles**

CANYONLANDS NATIONAL PARK, UT

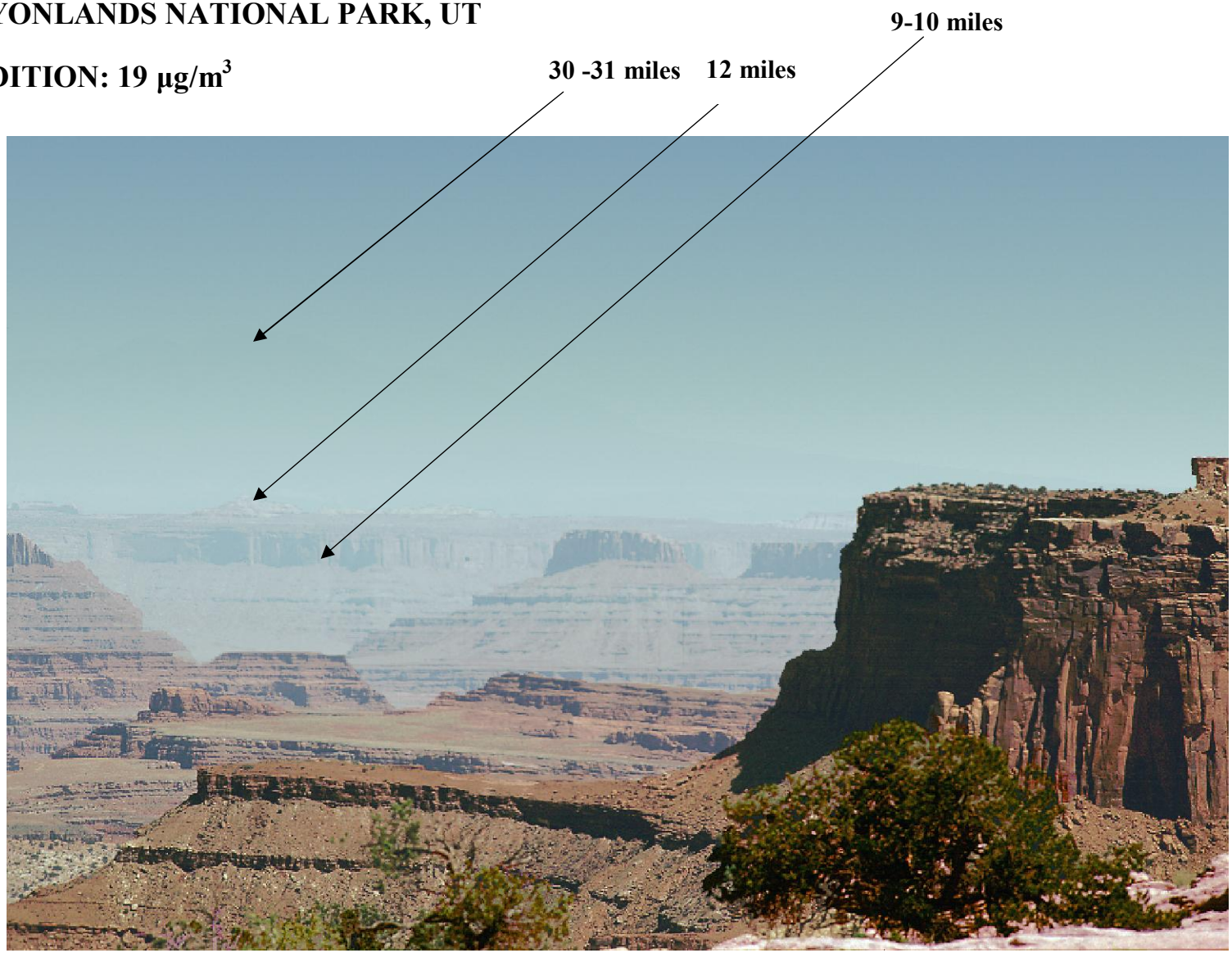
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**20% - 30%**
Visual Range	**25.1 miles**

CANYONLANDS NATIONAL PARK, UT

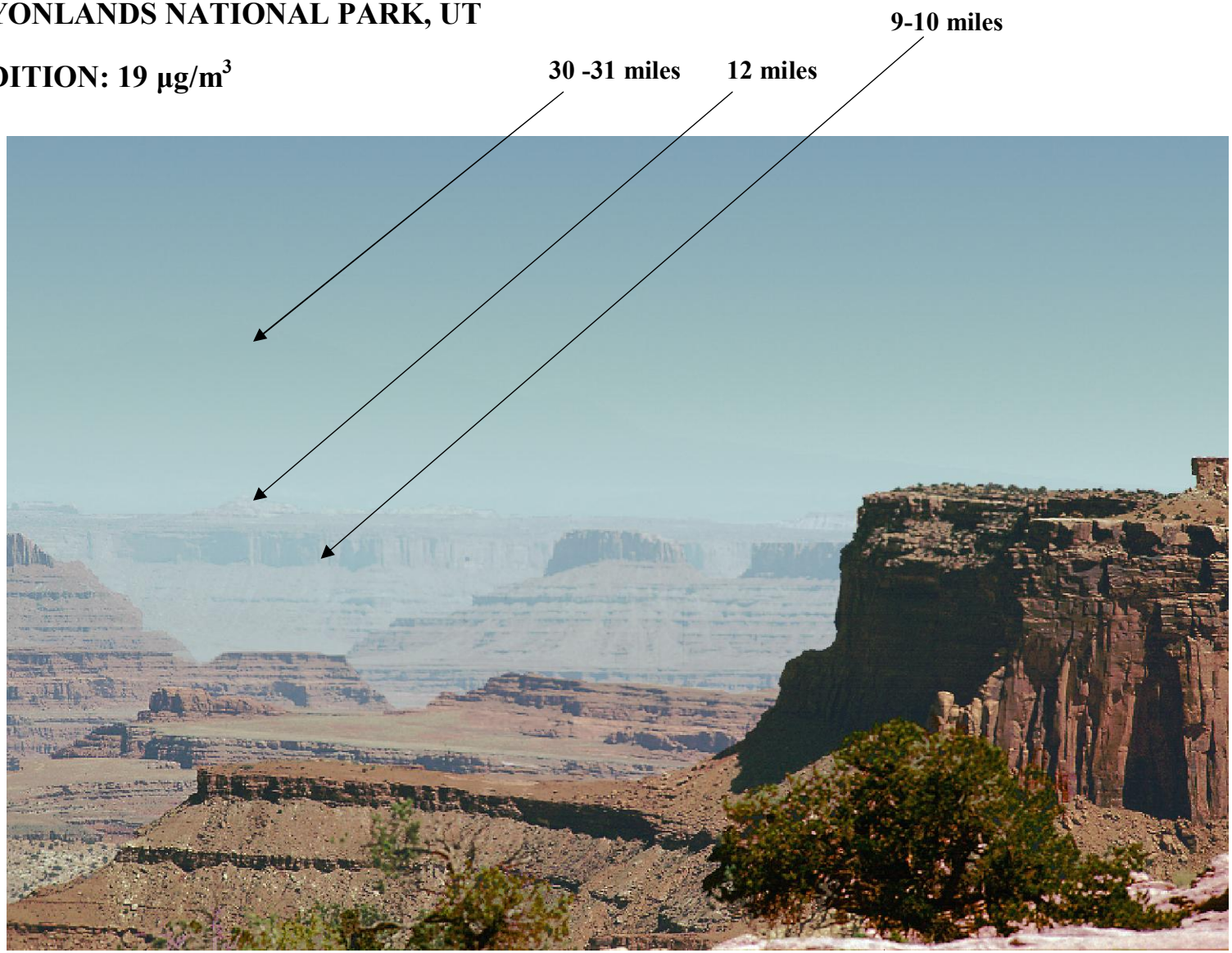
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**40 %**
Visual Range	**25.0 miles**

CANYONLANDS NATIONAL PARK, UT

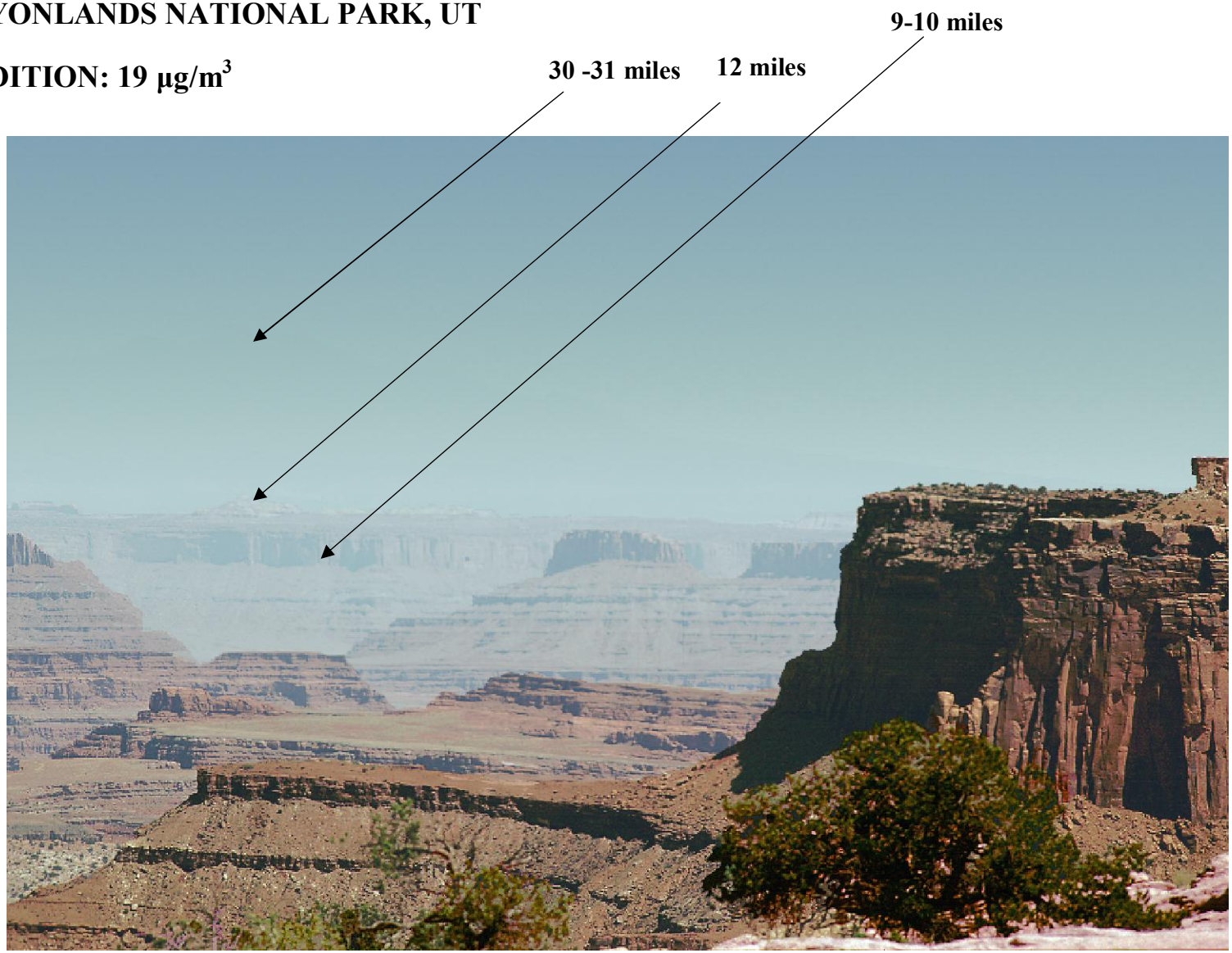
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**50 %**
Visual Range	**24.7 miles**

CANYONLANDS NATIONAL PARK, UT

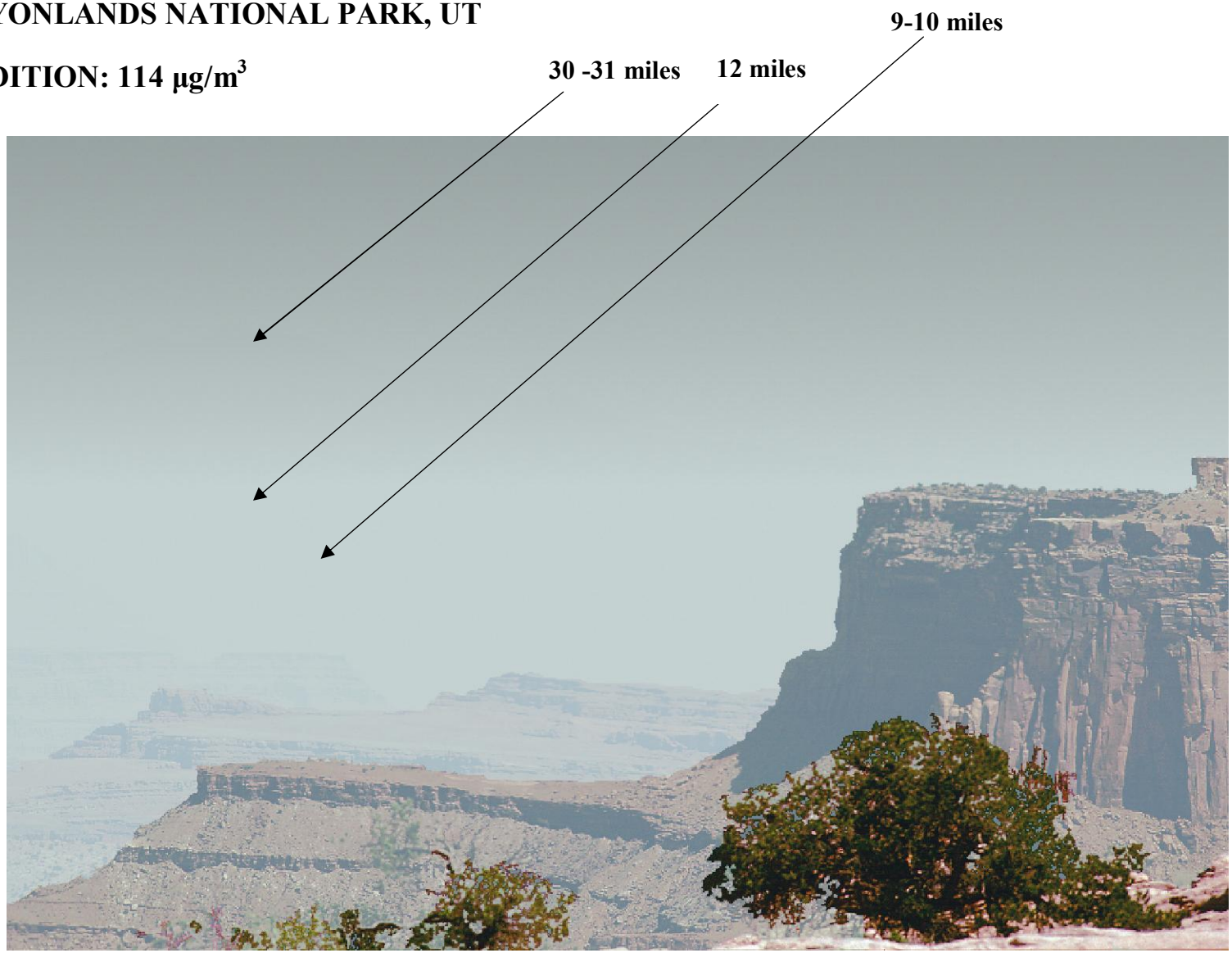
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**60 %**
Visual Range	**24.2 miles**

CANYONLANDS NATIONAL PARK, UT

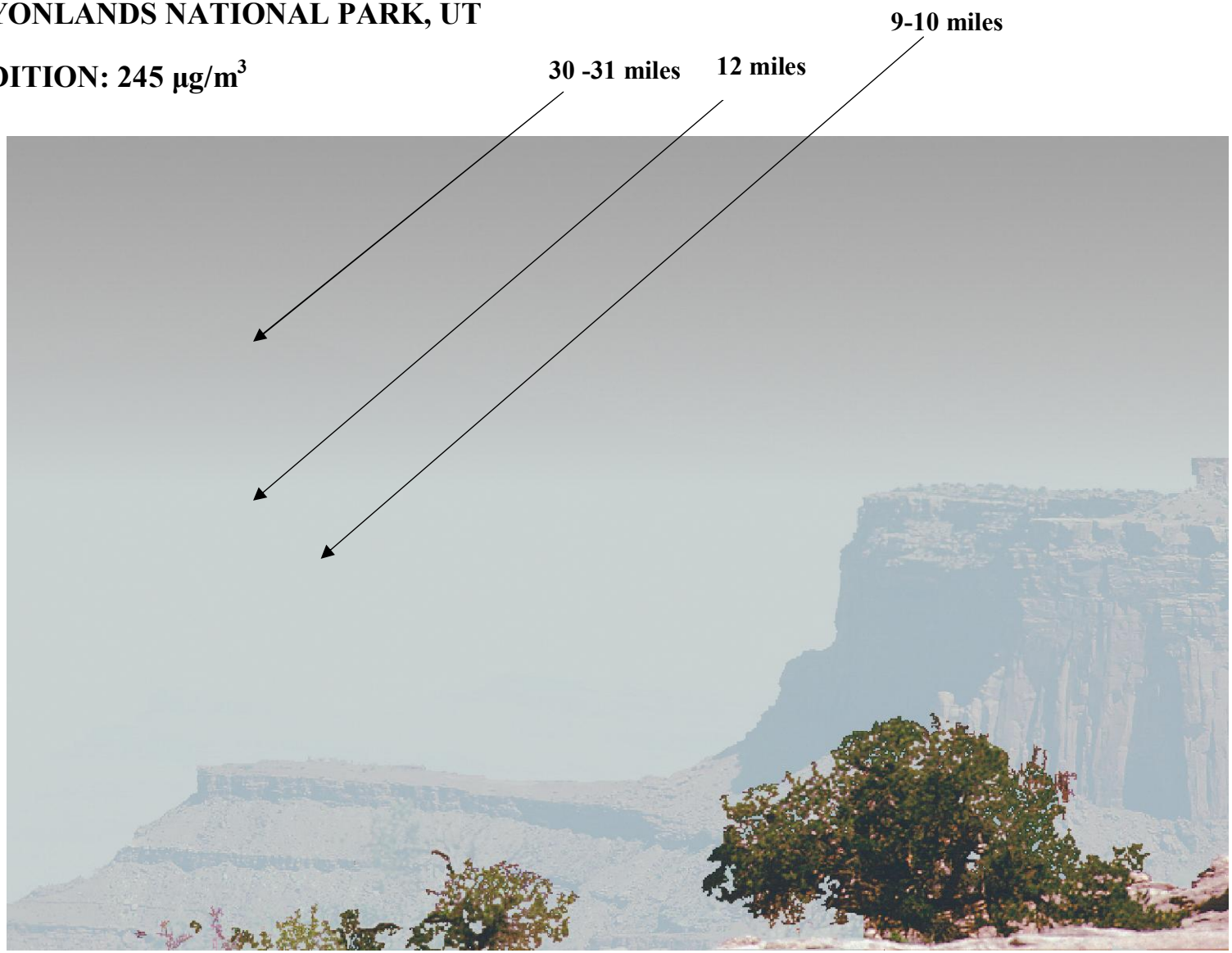
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**20% - 60%**
Visual Range	**4.4 miles**

CANYONLANDS NATIONAL PARK, UT

CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**20% - 60%**
Visual Range	**2.1miles**

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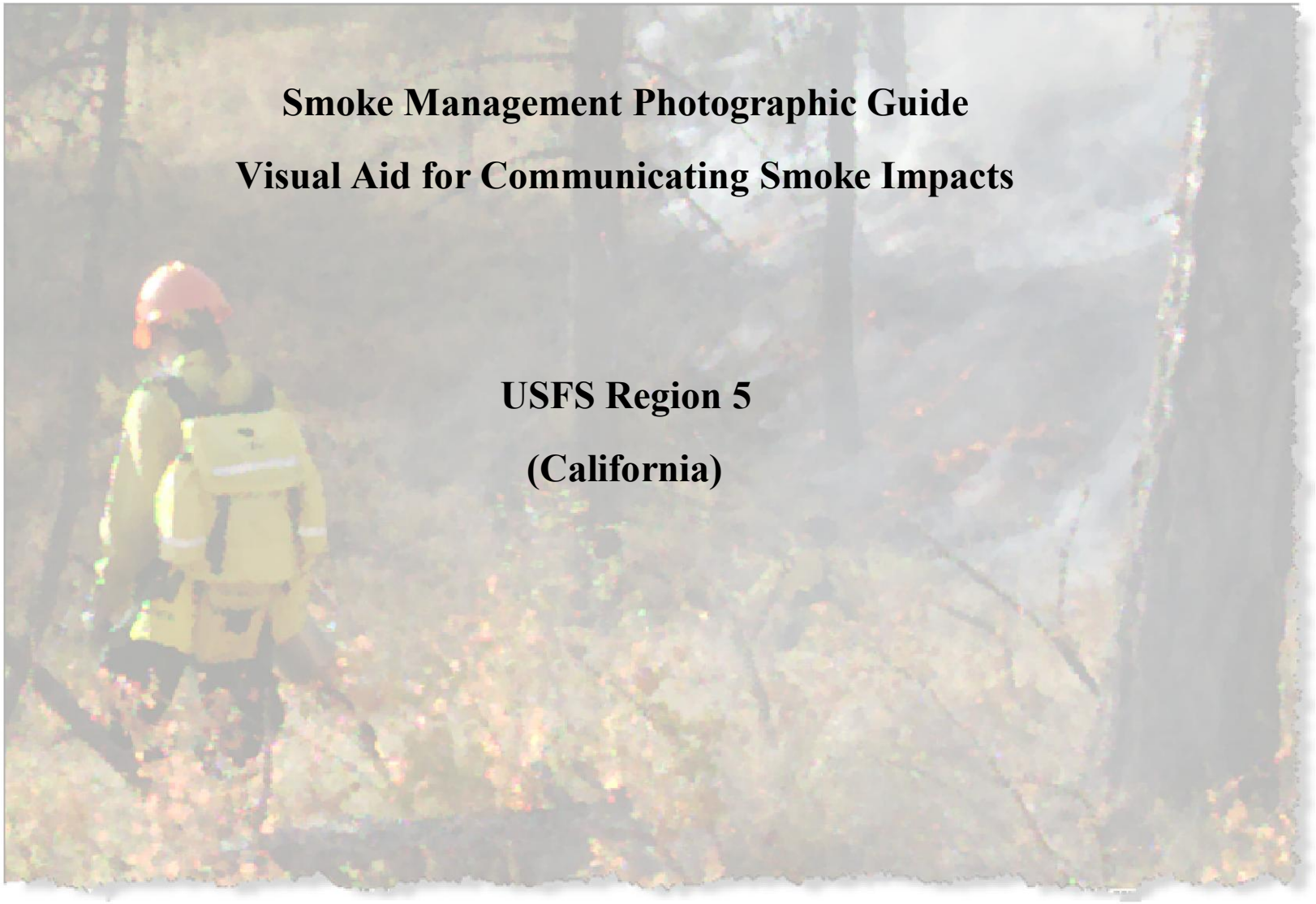


Smoke Management Photographic Guide

Visual Aid for Communicating Smoke Impacts

USFS Region 5

(California)

University of Idaho
College of Natural Resources

Development and Scope:
This guide is developed by the University of Idaho College of Natural Resources with images from US National Park and USDA Forest Service locations.

The primary purpose of this guide is to serve as a tool for communicating potential particulate matter (PM 2.5) levels using visual representation. Numerous factors impact visibility; in addition to particulate matter and the presence of ozone (Aherns 2003), visibility is also affected by compounds including ammonium nitrate, ammonium sulfate, and light absorbing carbon (Malm *et al*. 1994), as well as relative humidity (Achtemeier et al. 2001). Existing background levels of visibility also vary across the country (Core 2001). This guide is intended to indicate smoky conditions in USFS Region 5. Due to the complexity of variables, and limitations in the distances perceived by the human eye, visual approximations should be used as indicators, not precise measurement.

Figure 1 The materials in this guide are for estimation purposes only and indented to represent the overall conditions in the highlighted regions.

Methods
To represent visual impacts from smoke in numerous locations across the Unites States this reference guide has been generated using WinHaze imaging software (Air Resource Specialists Inc. 2013). This software package incorporates several years of particulate data from Class I airsheds throughout the continental United States. The program allows for consistent visual representation of airsheds under varying humidity, background pollutant levels and particulate matter (PM) concentrations based on the IMPROVE equation for estimating ambient light extinction coefficients (Hand and Malm 2006). This methodology facilitates consistent representation of smoky conditions while avoiding variations in sun angle and camera placement that can occur using a more traditional method of matching photographs with monitoring data. Yosemite National Park was chosen for this guide based on 951 days of particulate data incorporated into the visual estimates. To establish an image representing the area free of any smoke-impaired visibility a 'baseline' image was generated in WinHaze using the mean values indicated in the table on the left which total less than 5 $\mu g/m^3$ fine particulate matter and less than 5 $\mu g/m^3$ of coarse particulates.

Constituents of PM represented herein ($\mu g/m^3$)		
	Baseline	Elevated
Ammonium Sulfate	0.23	1.9
Ammonium Nitrate	0.1	0.94
Organic Carbon	0.49	-
LAC/Black Carbon	0.1	-
Fine Soil	0.11	1.04
Coarse mass	2.54	7.64

Visual impairment from smoke is simulated first by establishing constant values for the constituent of PM unlikely to change as the result of smoke from fires. 'Elevated' values for ammonium sulfate, ammonium nitrate, fine soil, and coarse mass were determined by using values recorded for the 20% worst visibility days. Organic carbon and Black carbon are then increased to reflect increasing concentrations of smoke, as this carbon composes nearly 75% of the emissions from forest fires (Andreae & Merlet 2001). The ratio of organic carbon to black carbon will be represented by a 15.4/1 ratio based on estimates for wildland fire in non-tropical forests in a comprehensive review by Andreae & Merlet (2001).

Because relative humidity (RH) impacts visibility and changes throughout the fire season, a range of different RH levels is represented based on morning and afternoon averages. Data for these averages is taken from Blue Canyon, CA (NOAA 2013). Values between the months of May and September were chosen to represent the relative humidity levels most likely to be present during the wildland fire season.

This guide represents short-term (1-3 hour) exposure pollutant levels as presented the Wildfire Smoke, A Guide for Public Health Officials (Lipset *et al.* 2008). The categories ('Good', 'Moderate', etc.) use terminology based on the EPA's Air Quality Index (US EPA, 2009). Due to the difficulty of distinguishing a fine scale measurement such as particulate concentration by using eyesight alone, three values were chosen, each in the mid-range of a health effect index category (*below*).

EPA Values for PM		Concentrations	
AQI Value	Actions to protect your health from particle pollution	PM2.5 or PM10 Levels ($\mu g/m^3$) 1 to 3 hour average	
Good (0-50)	None	0-38	19 $\mu g/m^3$
Moderate (51-100)	Unusually sensitive people should consider reducing prolonged or heavy exertion.	39-88	
Unhealthy for Sensitive Groups 101-150	The following groups should reduce prolonged or heavy outdoor exertion: -People with heart or lung disease -Children and older adults Everyone else should limit prolonged or heavy exertion	89-138	114 $\mu g/m^3$
Unhealthy (151-200)	The following groups should avoid all physical outdoors: -People with heart or lung disease -Children and older adults Everyone else should avoid prolonged or heavy exertion	139-351	245 $\mu g/m^3$
Very Unhealthy (201-300)	The following groups should remain indoors and keep activity levels low: -People with heart or lung disease -Children and older adults Everyone else should avoid all physical activity outdoors	352-526+	

Using this guide:

To use this guide to represent particulate matter, compare your line of site with landmarks similar distances as those depicted here-in. When making this comparison, face away from the sun. Use points on the landscape of known distances that you are familiar with. Several examples of the same concentration are represented with varying relative humilities based on what is likely to be encountered during the fire season.

YOSEMITE NATIONAL PARK, CA

CONDITION: Good, 19.0 µg/m³

PM 2.5	**19.0 µg/m³**
Relative Humidity	**30%**
Visual Range	**29.2 miles**

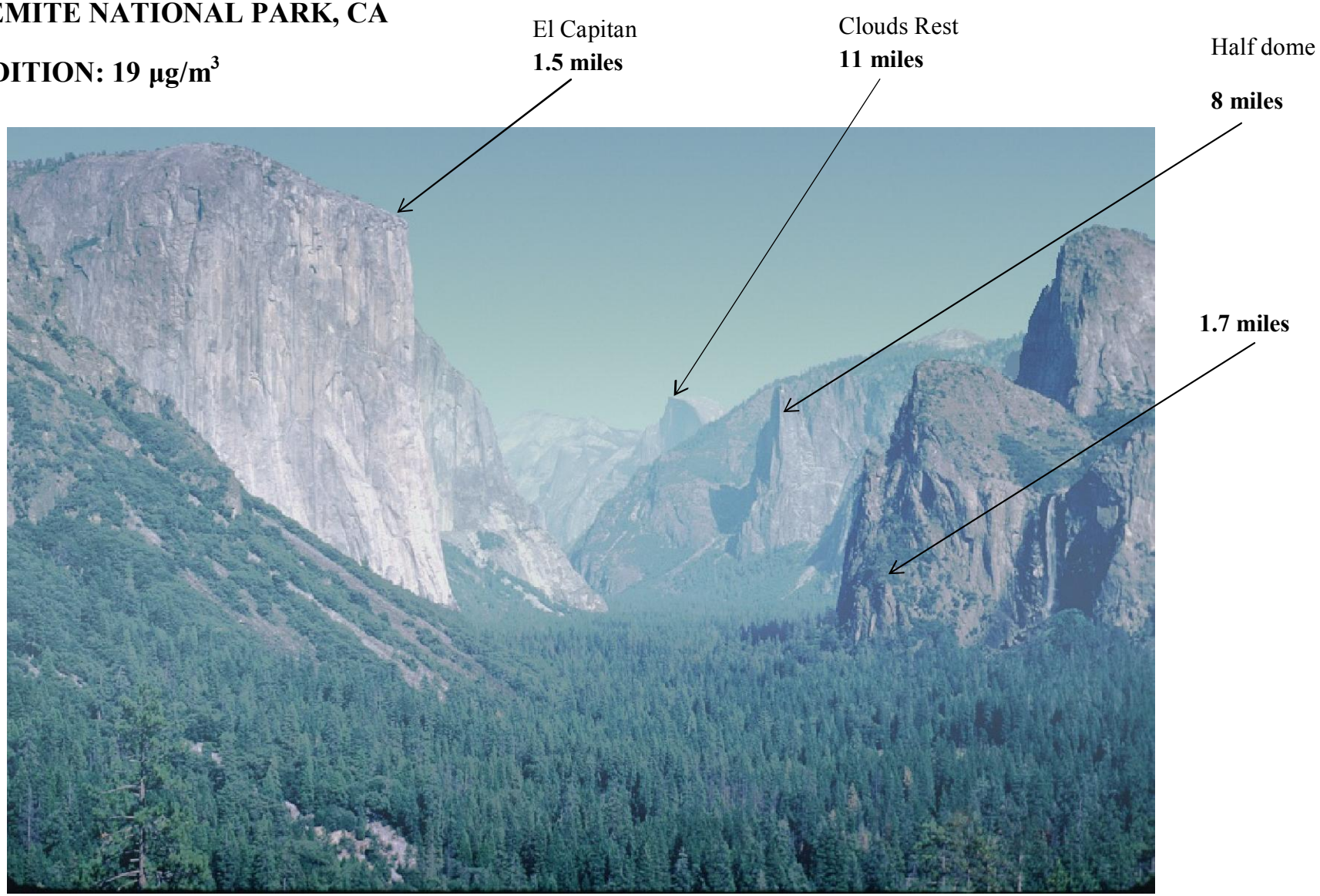
YOSEMITE NATIONAL PARK, CA

CONDITION: Baseline, <5 µg/m^3

PM 2.5	**<5.0 µg/m^3**
Relative Humidity	**30%**
Visual Range	**152.9 miles**

YOSEMITE NATIONAL PARK, CA

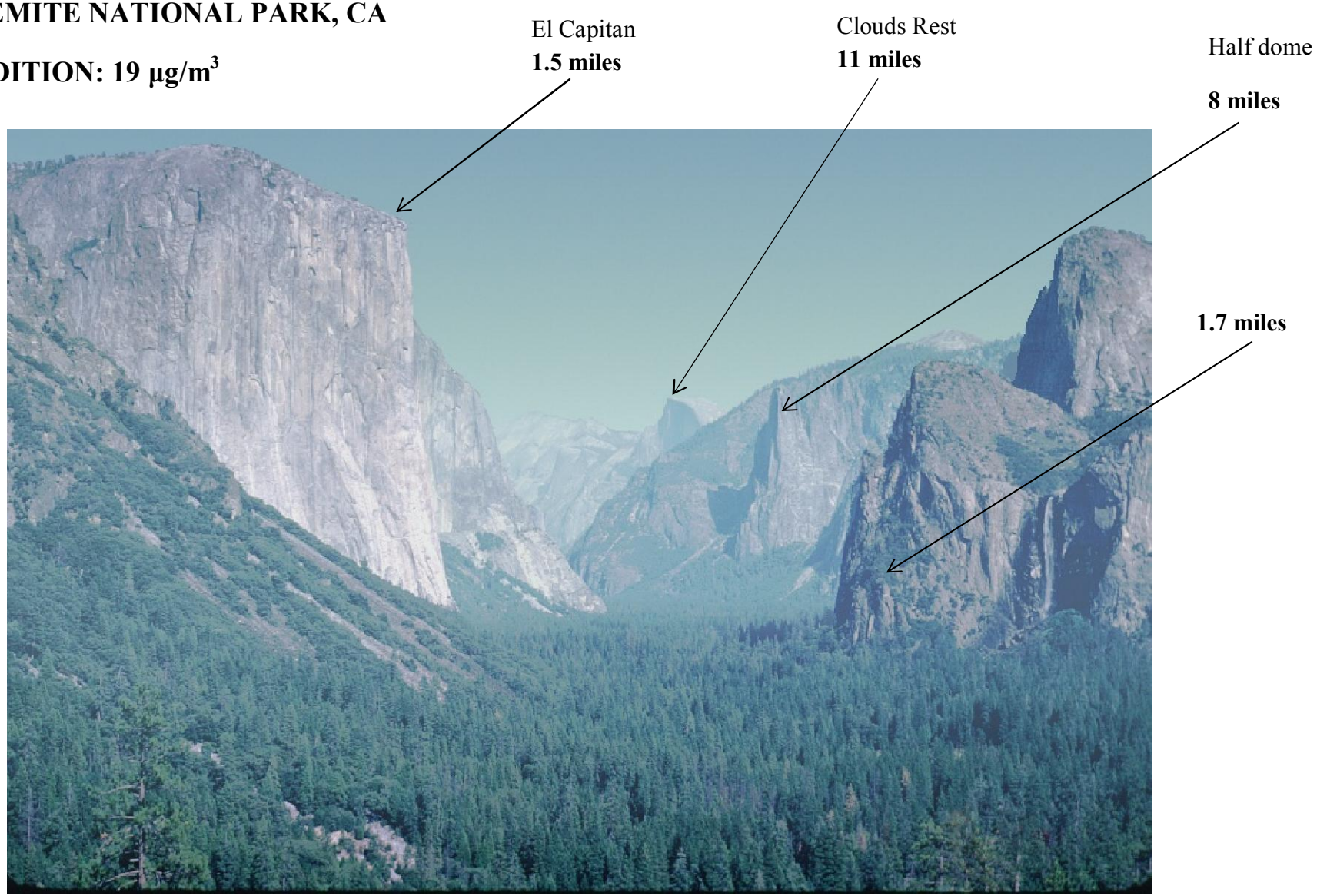
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**30%**
Visual Range	**27.0 miles**

YOSEMITE NATIONAL PARK, CA

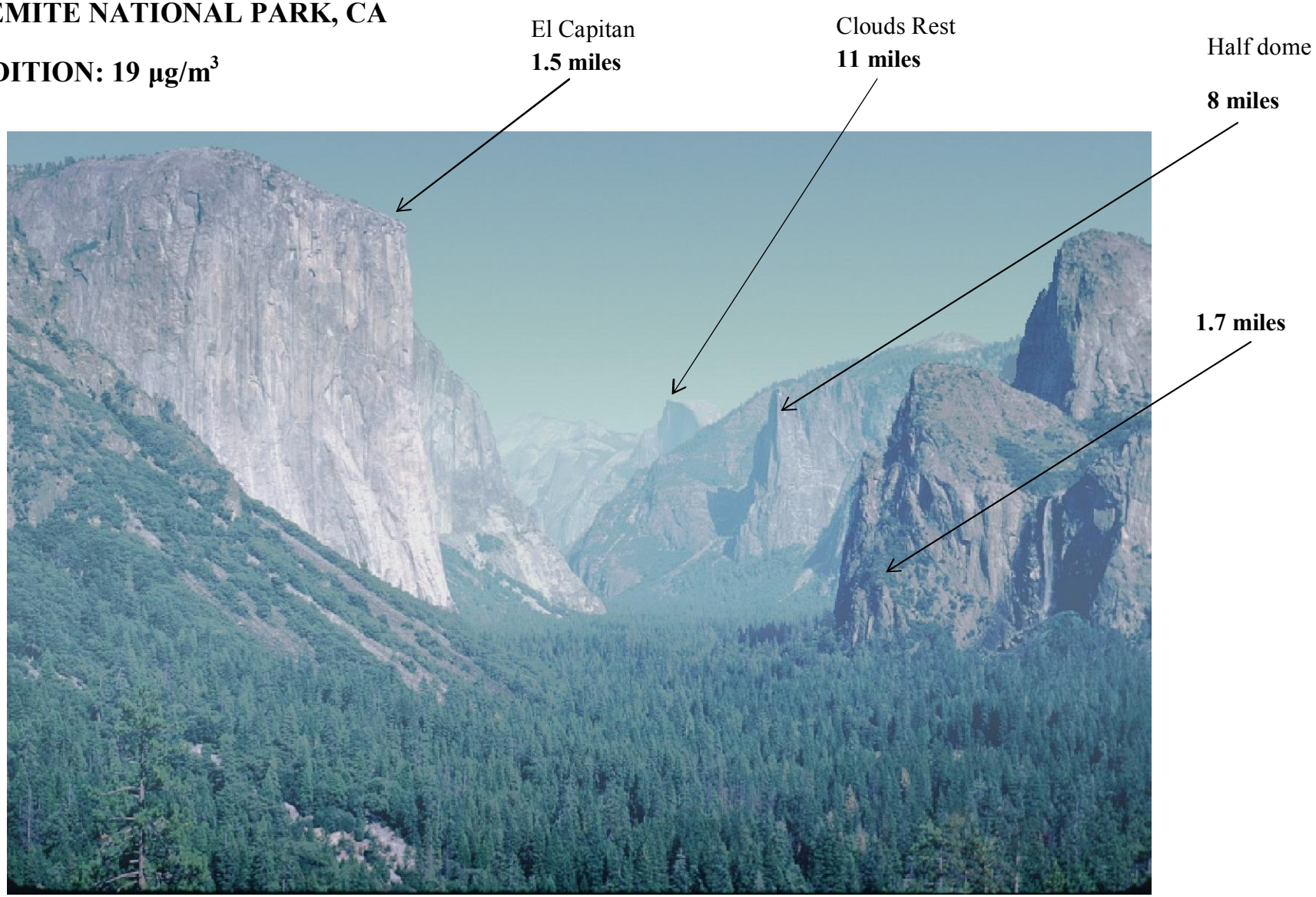
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**40%**
Visual Range	**26.8 miles**

YOSEMITE NATIONAL PARK, CA

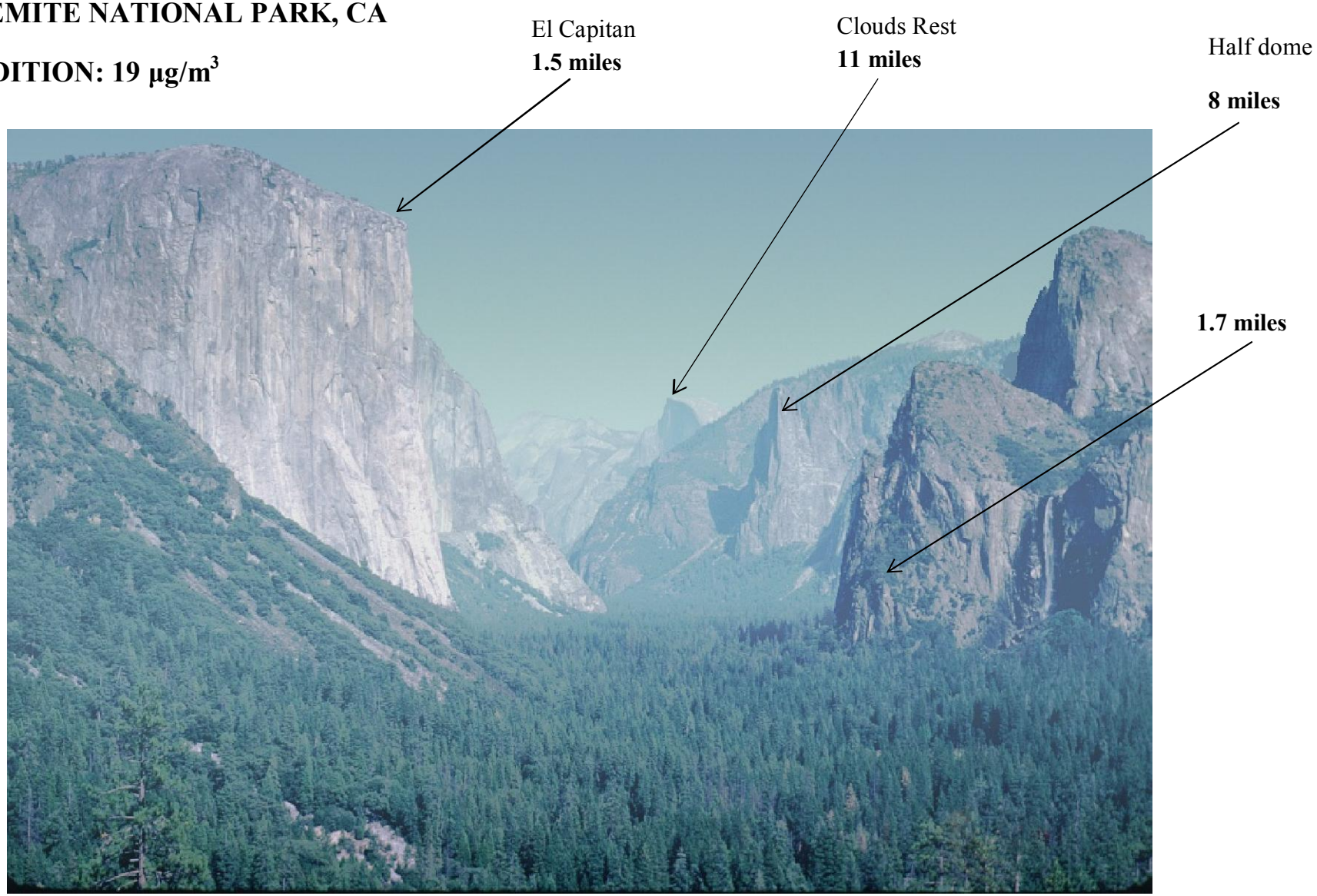
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**50%**
Visual Range	**26.2 miles**

YOSEMITE NATIONAL PARK, CA

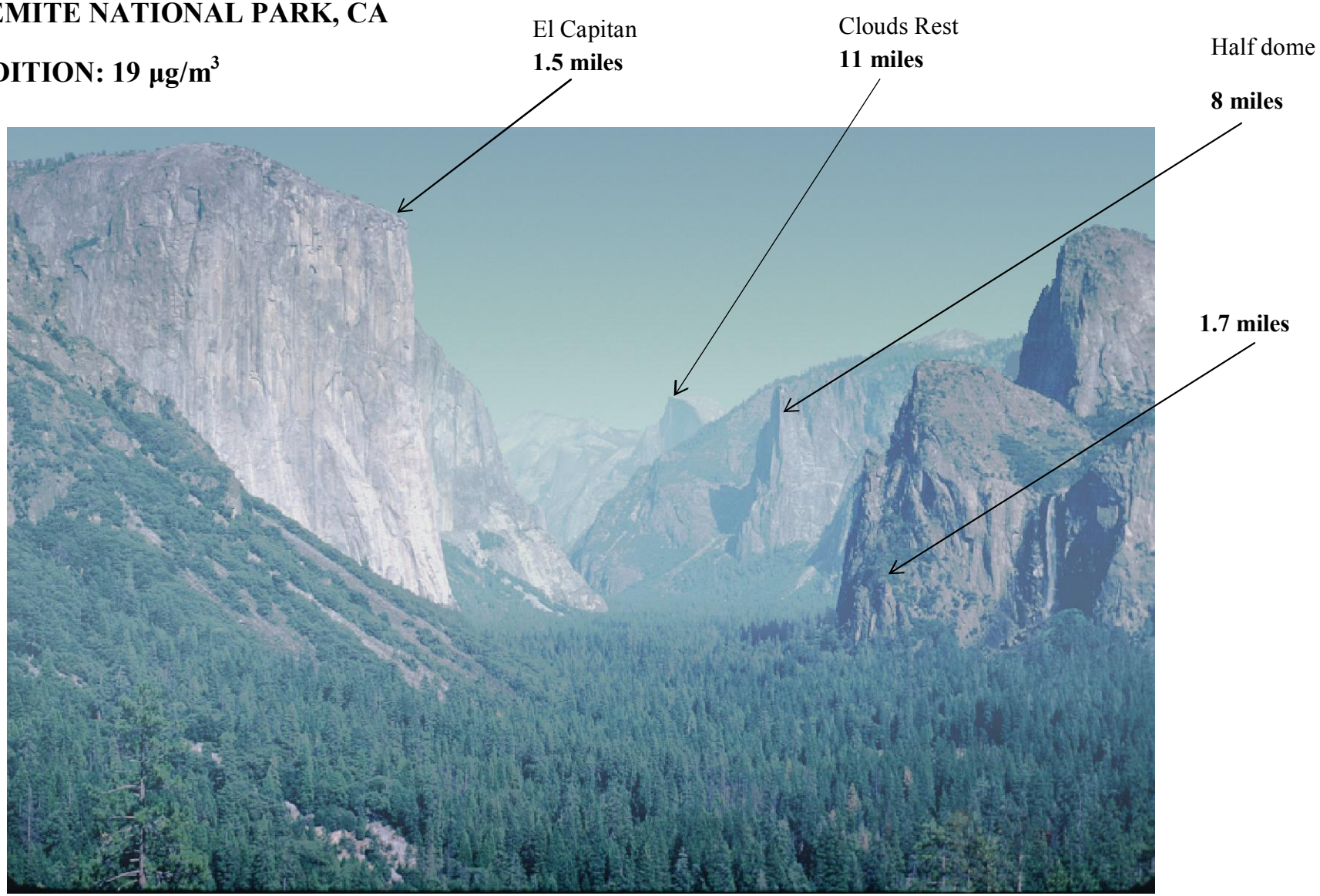
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**60%**
Visual Range	**25.4 miles**

YOSEMITE NATIONAL PARK, CA

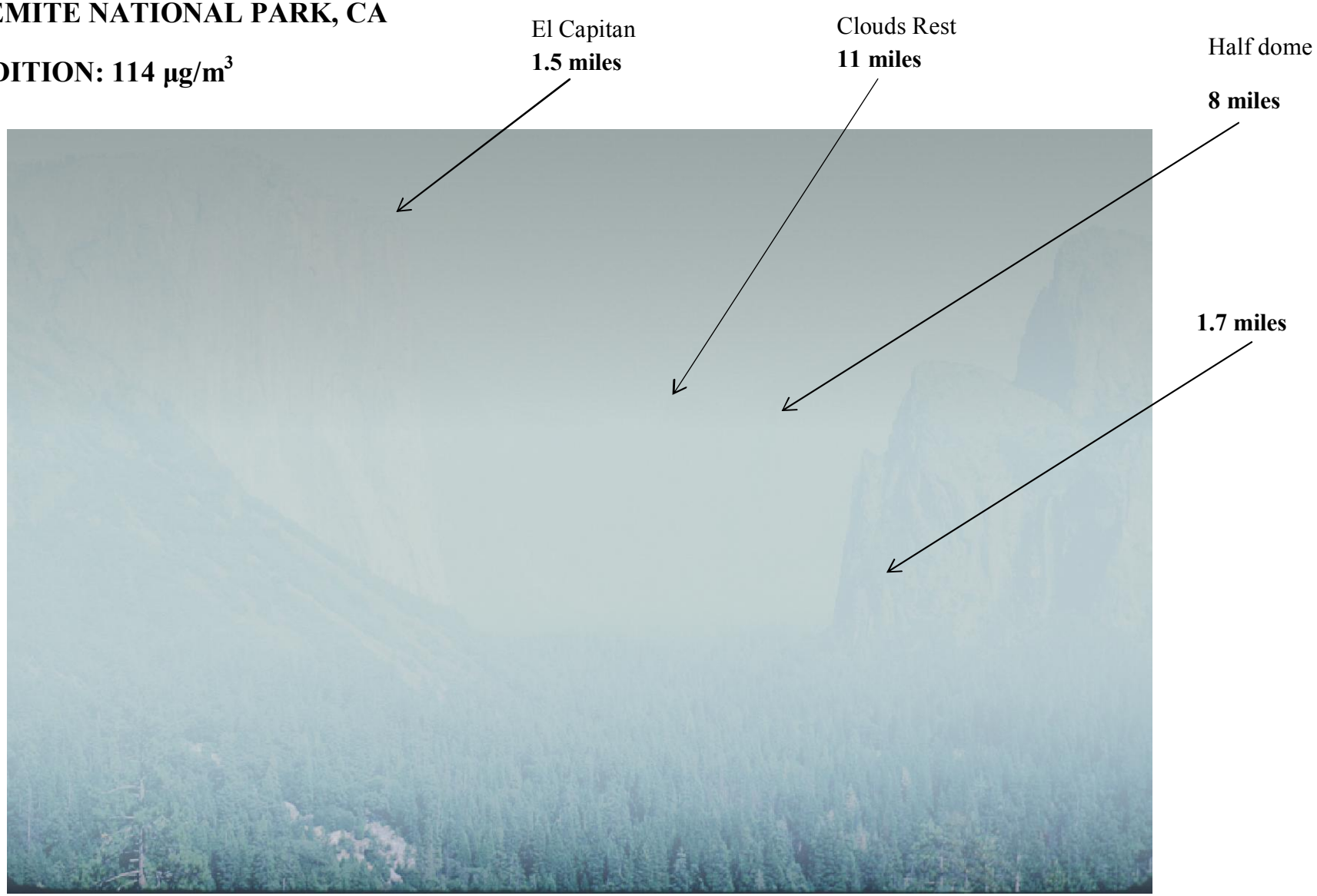
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**70%**
Visual Range	**24.4 miles**

YOSEMITE NATIONAL PARK, CA

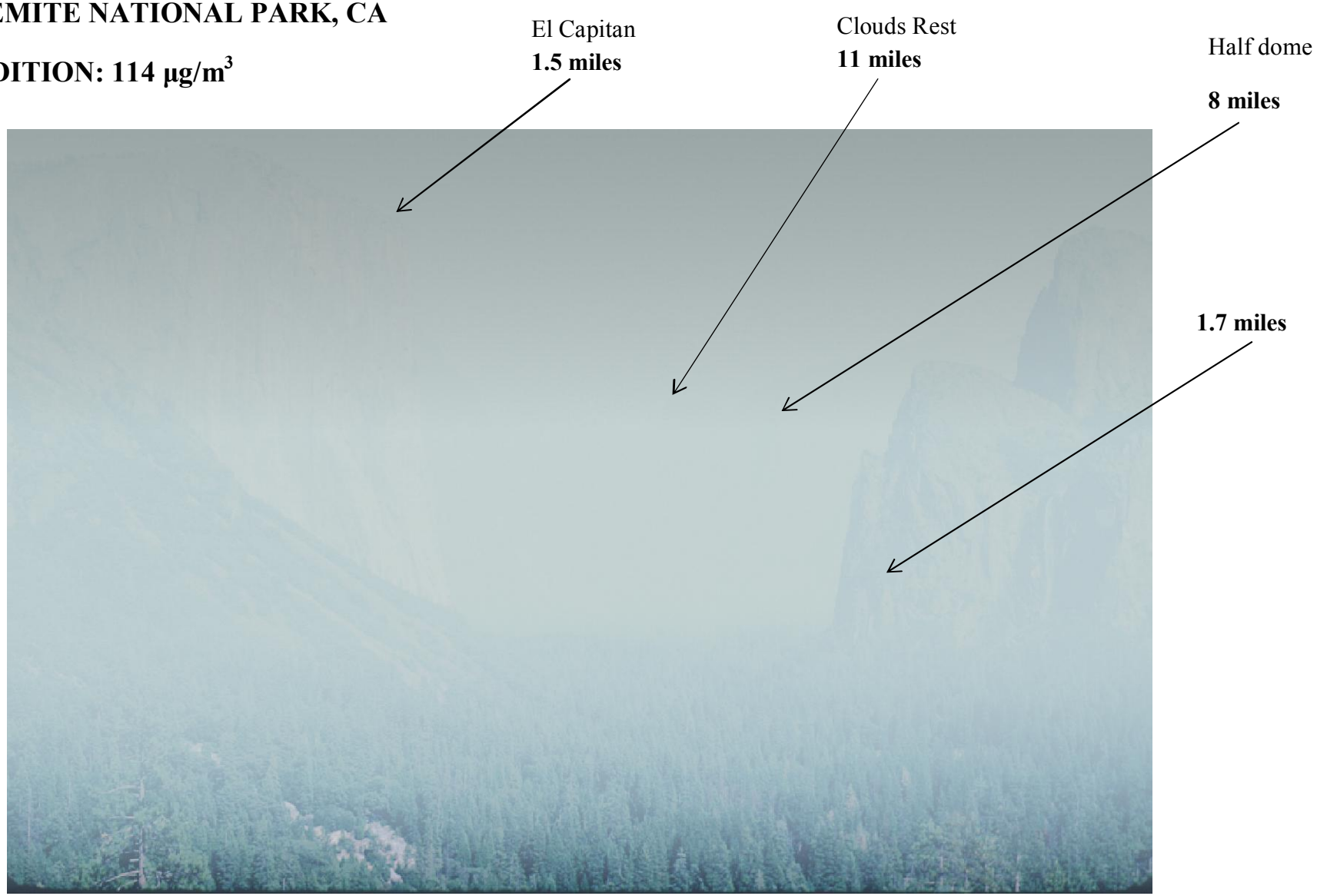
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**30% - 60%**
Visual Range	**4.8 miles**

YOSEMITE NATIONAL PARK, CA

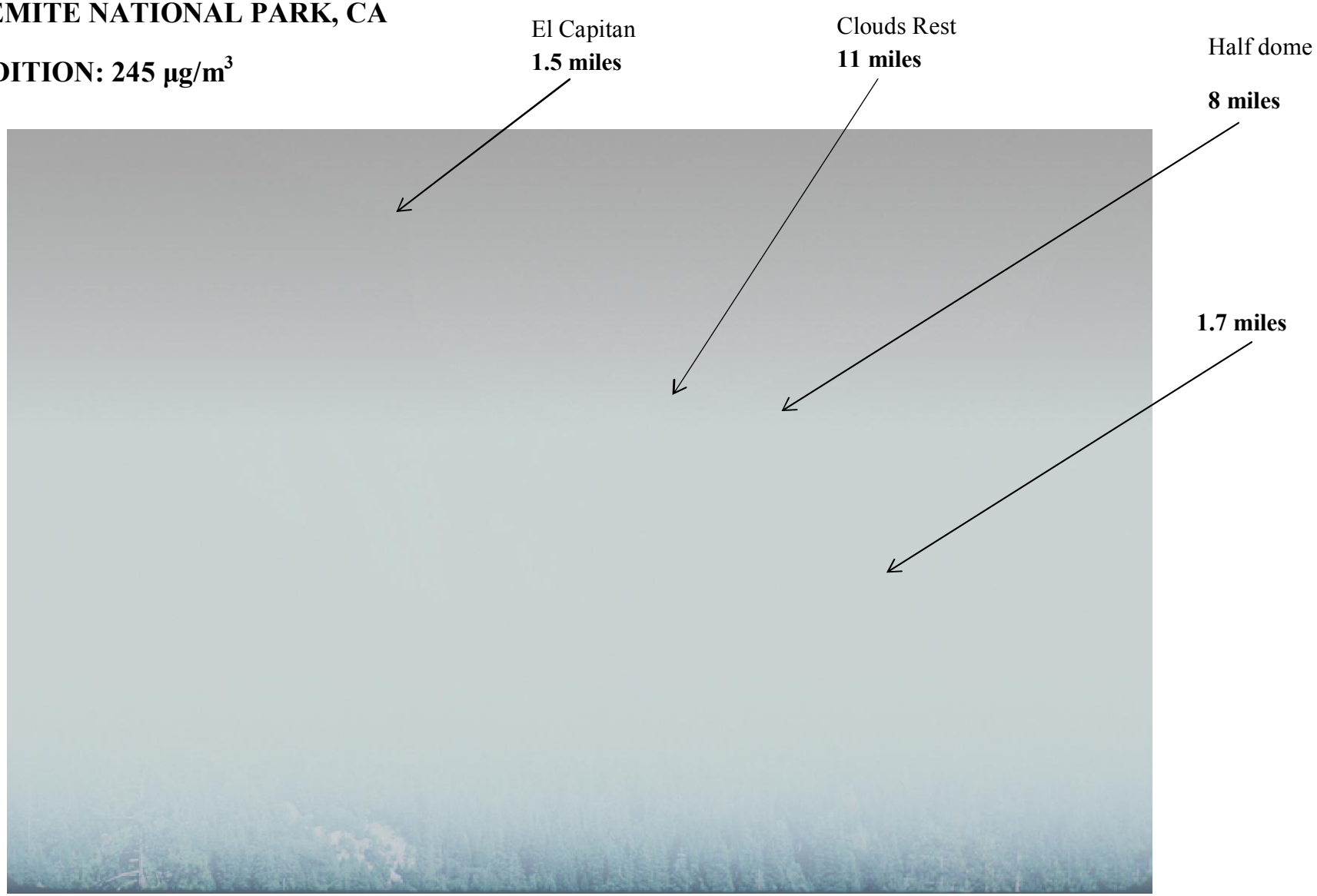
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**70%**
Visual Range	**4.7 miles**

YOSEMITE NATIONAL PARK, CA

CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**30% or more**
Visual Range	**2.3 miles or less**

References

Air Resources Incorporated. 2013. Resources and Software Downloads. Accessed 28 March 2013. Available at: http://www.air-resource.com/resources/downloads.html.

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Hand J.L. and Malm, W.C. 2006. Review of the IMPROVE Equation for Estimating Ambient Light Extinction Coefficients – Final Report. Accessed on 10 May 2013. Available online at: http://vista.cira.colostate.edu/improve/publications/graylit/016_IMPROVEeqReview/IMPROVEeqReview.htm.

Lipsett, Michael, Materna, Barbara, Stone, Susan L., Therriault, Shannon, Blaisdell, Robert, Cook, Jeff, Waldman, Jed, Wohl-Sanchez, Lauren, Kent, Lani, Jenkins, Peggy, Westerdahl, Dane, Phillips, Tom, Smith, Linda, Behrman, Jim, DuTeaux, Shelly, Lam, Richard, Gold, Deborah, Nakamura, Bob, Smith, Alisa, Brauer, Michael. 2008. Wildfire Smoke A Guide for Public Health Officials. 53 p.

Malm, William C, Sisler, James F., Huffman, Dale, Eldred, Robert A, and Cahil, Thomas A. 1994. Spatial and seasonal trended in particle concentration and optical extinction in the United States. Journal of Geophysical Research, **99**,D1 1347-1370.

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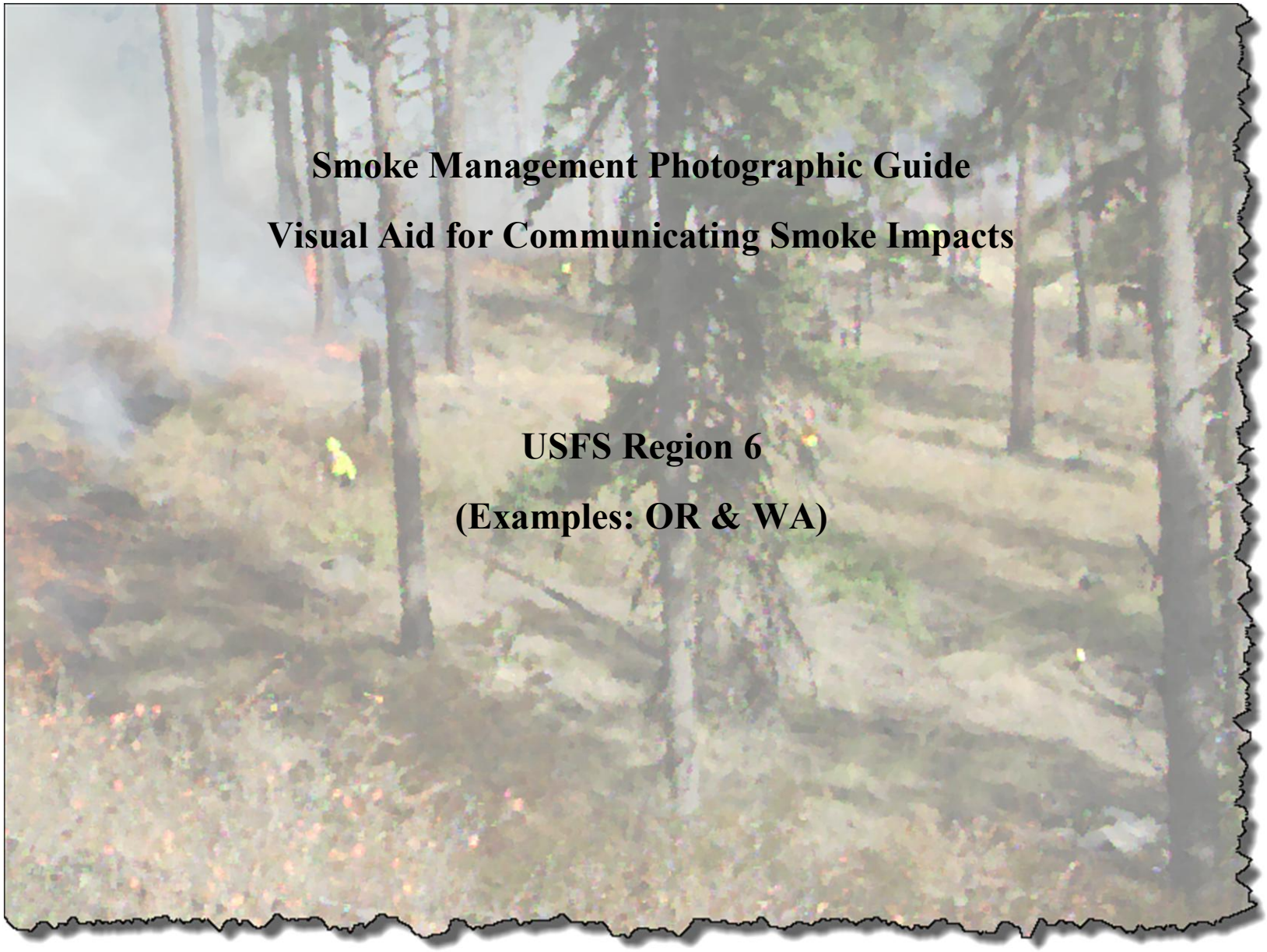
United States Environmental Protection Agency. 2009. Air Quality Index, A Guide to Air Quality and Your Health. EPA-456/F-09-002. 12 p.



Smoke Management Photographic Guide

Visual Aid for Communicating Smoke Impacts

USFS Region 6

(Examples: OR & WA)

University of Idaho
College of Natural Resources

Development and Scope:
This guide is developed by the University of Idaho College of Natural Resources with images from US National Park and USDA Forest Service locations.

The primary purpose of this guide is to serve as a tool for communicating potential particulate matter (PM 2.5) levels using visual representation. Numerous factors impact visibility; in addition to particulate matter and the presence of ozone (Aherns 2003), visibility is also affected by compounds including ammonium nitrate, ammonium sulfate, and light absorbing carbon (Malm *et al.* 1994), as well as relative humidity (Achtemeier et al. 2001). Existing background levels of visibility also vary across the country (Core 2001). This guide is intended to indicate smoky conditions in USFS Region 6. Due to the complexity of variables, and limitations in the distances perceived by the human eye, visual approximations should be used as indicators, not precise measurement.

Figure 1 The materials in this guide are for estimation purposes only and indented to represent the overall conditions in the highlighted regions.

Methods
To represent visual impacts from smoke in numerous locations across the Unites States this reference guide has been generated using WinHaze imaging software (Air Resource Specialists Inc. 2013). This software package incorporates several years of particulate data from Class I airsheds throughout the continental United States. The program allows for consistent visual representation of airsheds under varying humidity, background pollutant levels and particulate matter (PM) concentrations based on the IMPROVE equation for estimating ambient light extinction coefficients (Hand and Malm 2006). This methodology facilitates consistent representation of smoky conditions while avoiding variations in sun angle and camera placement that can occur using a more traditional method of matching photographs with monitoring data. Images from the Columbia River Gorge and Snoqualmie Pass were chosen for this guide based on 551 and 353 days of particulate data, respectively. To establish an image representing the area free of any smoke-impaired visibility a 'baseline' image was generated in WinHaze using the mean values indicated in the table on the left which total less than 5 $\mu g/m^3$ fine particulate matter and less than 5 $\mu g/m^3$ of coarse particulates. Baseline and elevated values for Snoqualmie pass are displayed following the OR visibility images.

Constituents of PM represented herein ($\mu g/m^3$)		
	Baseline	Elevated
Ammonium Sulfate	0.54	2.56
Ammonium Nitrate	0.25	1.78
Organic Carbon	0.91	-
LAC/Black Carbon	0.24	-
Fine Soil	0.24	1.28
Coarse mass	5.02	11.88

Visual impairment from smoke is simulated first by establishing constant values for the constituent of PM unlikely to change as the result of smoke from fires. 'Elevated' values for ammonium sulfate, ammonium nitrate, fine soil, and coarse mass were determined by using values recorded for the 20% worst visibility days. Organic carbon and Black carbon are then increased to reflect increasing concentrations of smoke, as this carbon

composes nearly 75% of the emissions from forest fires (Andreae & Merlet 2001). The ratio of organic carbon to black carbon will be represented by a 15.3/1 ratio based on estimates for wildland fire in non-tropical forests in a comprehensive review by Andreae & Merlet (2001).

Because relative humidity (RH) impacts visibility and changes throughout the fire season, a range of different RH levels is represented based on morning and afternoon averages. Data for these averages is taken from Portland for the Oregon examples, and SeaTac Airport for the Washington examples. (NOAA 2013). Values between the months of May and September were chosen to represent the relative humidity levels most likely to be present during the wildland fire season.

This guide represents short-term (1-3 hour) exposure pollutant levels as presented the Wildfire Smoke, A Guide for Public Health Officials (Lipset *et al.* 2008). The categories ('Good', 'Moderate', etc.) use terminology based on the EPA's Air Quality Index (US EPA, 2009). Due to the difficulty of distinguishing a fine scale measurement such as particulate concentration by using eyesight alone, three values were chosen, each in the mid-range of a health effect index category (*below*).

EPA Values for PM		Concentrations	
AQI Value	Actions to protect your health from particle pollution	PM2.5 or PM10 Levels ($\mu g/m^3$) 1 to 3 hour average	
Good (0-50)	None	0-38	19 $\mu g/m^3$
Moderate (51-100)	Unusually sensitive people should consider reducing prolonged or heavy exertion.	39-88	
Unhealthy for Sensitive Groups 101-150	The following groups should reduce prolonged or heavy outdoor exertion: -People with heart or lung disease -Children and older adults Everyone else should limit prolonged or heavy exertion	89-138	114 $\mu g/m^3$
Unhealthy (151-200)	The following groups should avoid all physical outdoors: -People with heart or lung disease -Children and older adults Everyone else should avoid prolonged or heavy exertion	139-351	245 $\mu g/m^3$
Very Unhealthy (201-300)	The following groups should remain indoors and keep activity levels low: -People with heart or lung disease -Children and older adults Everyone else should avoid all physical activity outdoors	352-526+	

Using this guide:

To use this guide to represent particulate matter, compare your line of site with landmarks similar distances as those depicted here-in. When making this comparison, face away from the sun. Use points on the landscape of known distances that you are familiar with. Several examples of the same concentration are represented with varying relative humilities based on what is likely to be encountered during the fire season.

COLUMBIA RIVER GORGE, OR

CONDITION: Baseline, <5 µg/m³

PM 2.5	**<5.0 µg/m³**
Relative Humidity	**40%**
Visual Range	**108.7 miles**

5

COLUMBIA RIVER GORGE, OR

CONDITION: Baseline, <5 µg/m^3

PM 2.5	**<5.0 µg/m^3**
Relative Humidity	**40%**
Visual Range	**108.7 miles**

COLUMBIA RIVER GORGE, OR

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**40 %**
Visual Range	**26.8 miles**

COLUMBIA RIVER GORGE, OR

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**50%**
Visual Range	**25.8 miles**

COLUMBIA RIVER GORGE, OR

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**60 %**
Visual Range	**24.7 miles**

COLUMBIA RIVER GORGE, OR

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**70 %**
Visual Range	**23.3 miles**

COLUMBIA RIVER GORGE, OR

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**80 %**
Visual Range	**21.7 miles**

COLUMBIA RIVER GORGE, OR

CONDITION: 114 µg/m^3

PM 2.5	**114 µg/m^3**
Relative Humidity	**40% - 50%**
Visual Range	**4.8 miles**

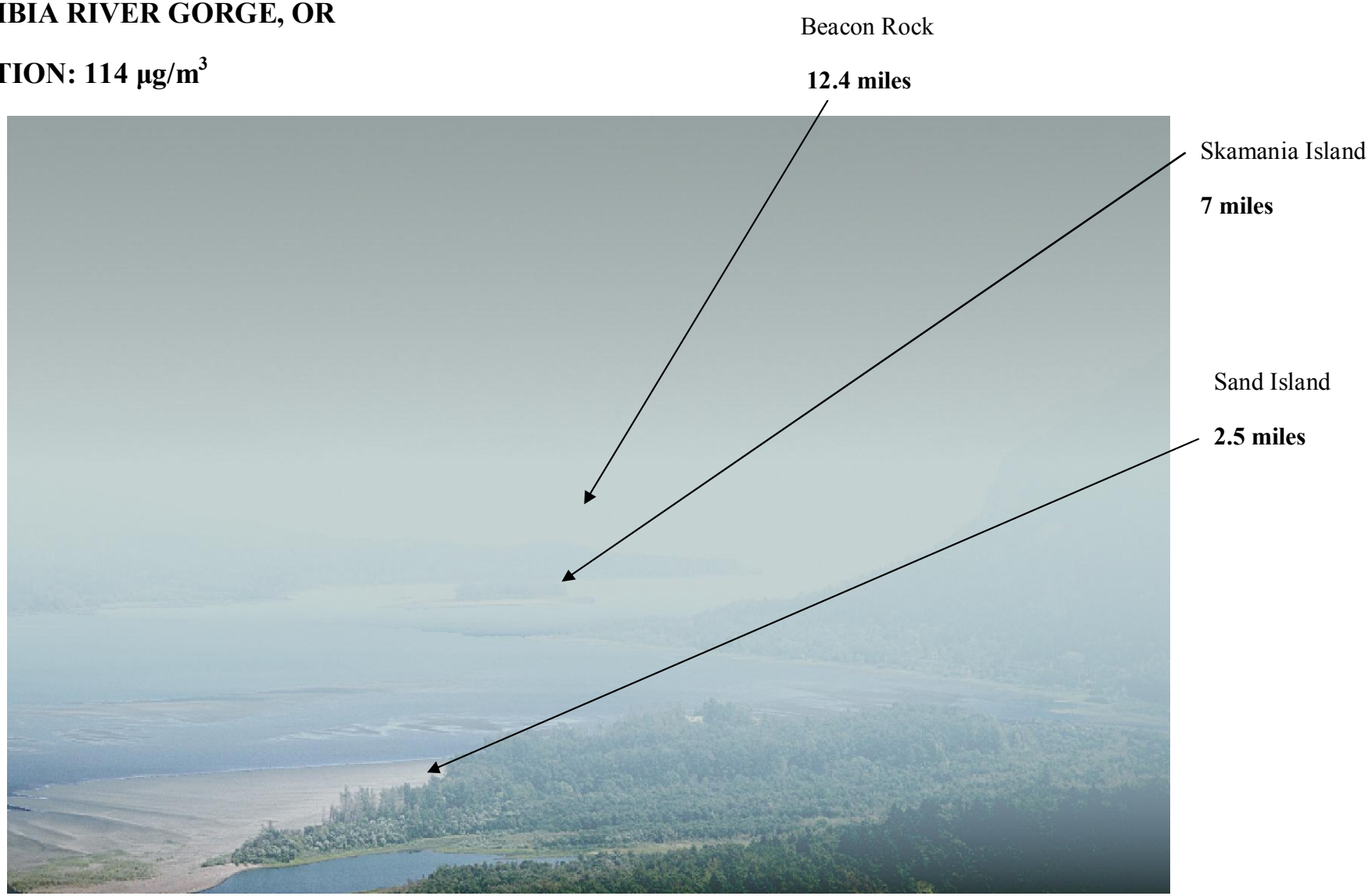
COLUMBIA RIVER GORGE, OR

CONDITION: 114 µg/m^3

PM 2.5	**114 µg/m^3**
Relative Humidity	**60% - 70%**
Visual Range	**4.7 miles**

COLUMBIA RIVER GORGE, OR

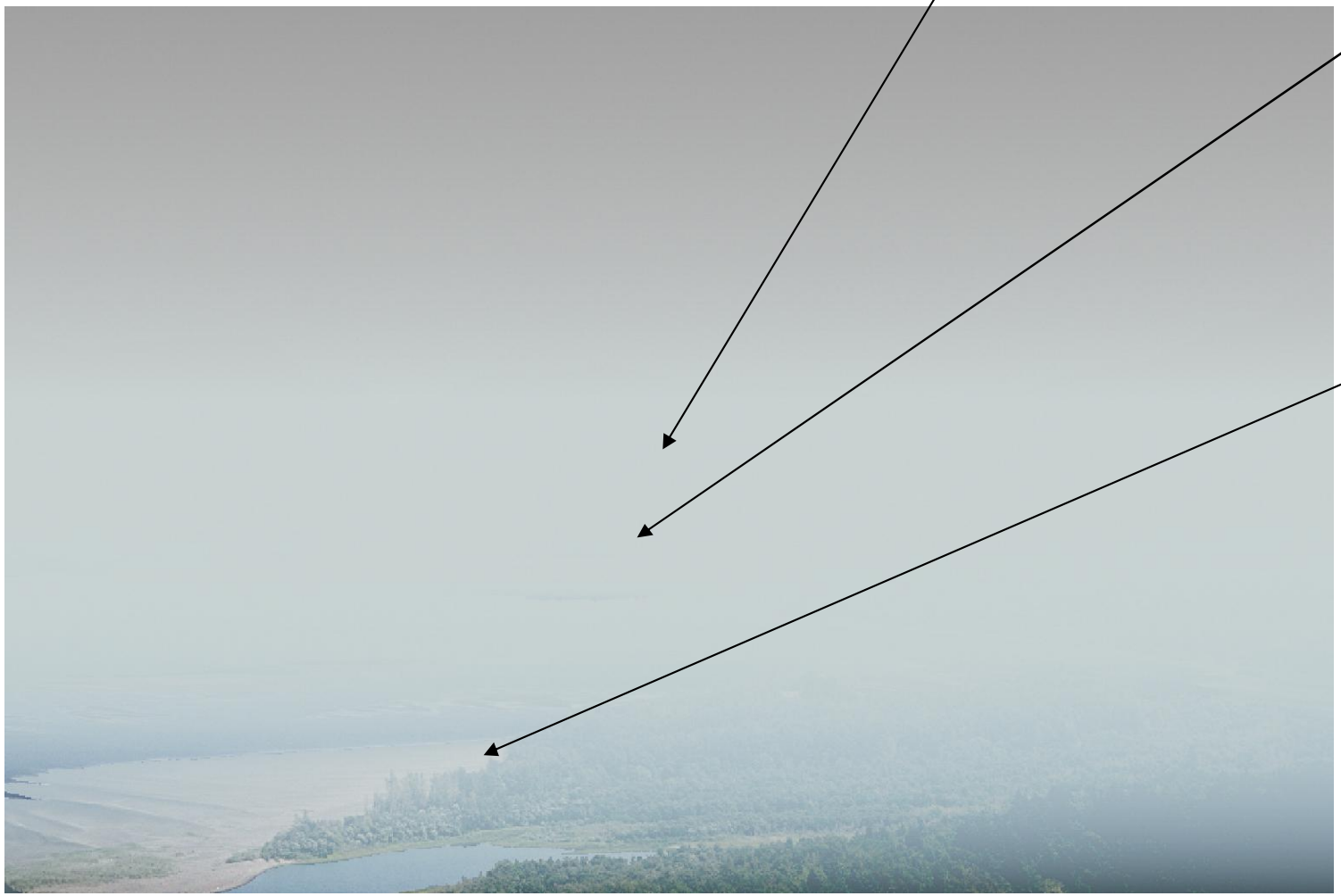
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**80 %**
Visual Range	**4.6 miles**

COLUMBIA RIVER GORGE, OR

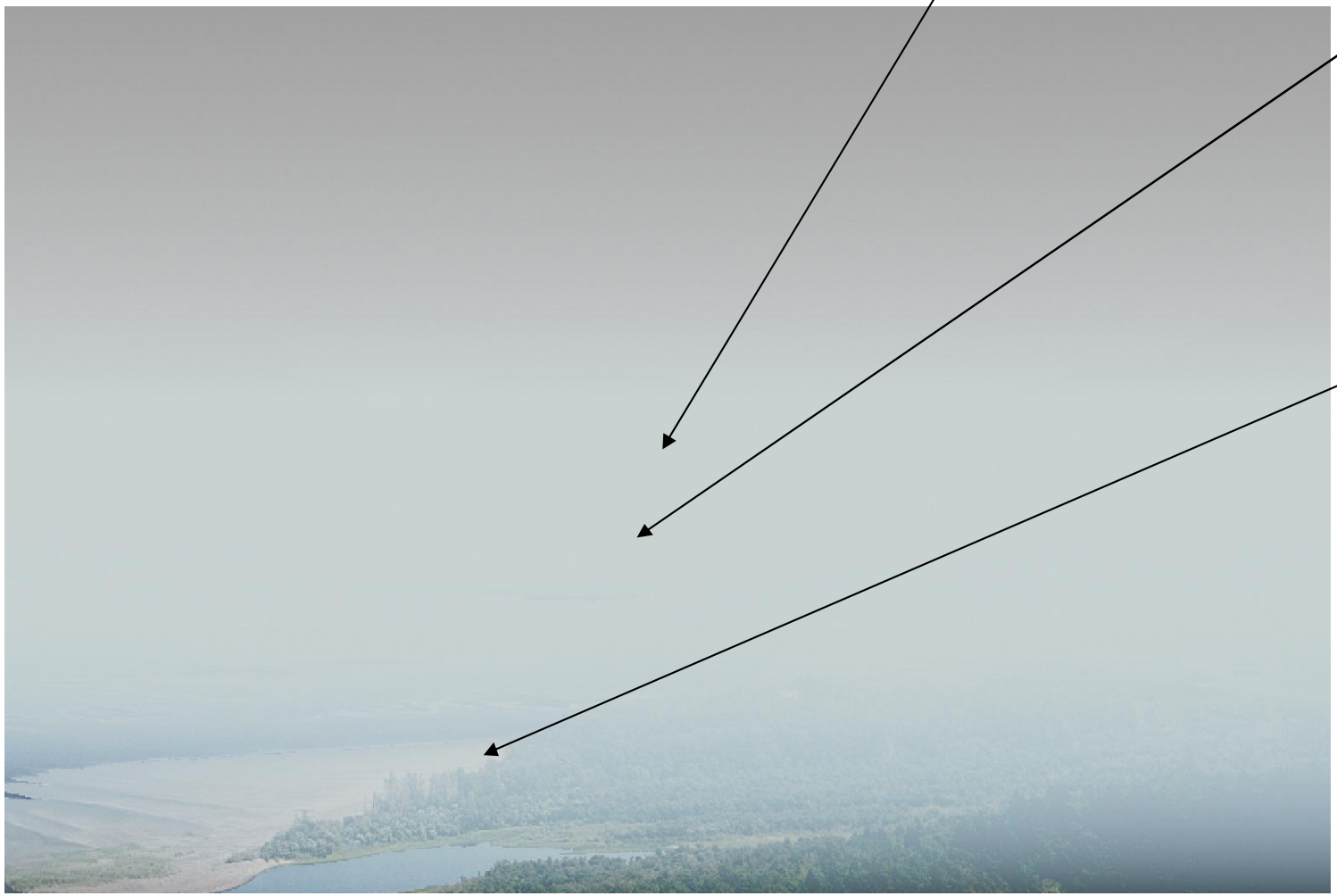
CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**40 %**
Visual Range	**2.3 miles**

COLUMBIA RIVER GORGE, OR

CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**50% - 80%**
Visual Range	**2.2 miles**

SNOWQUALMIE PASS, WA

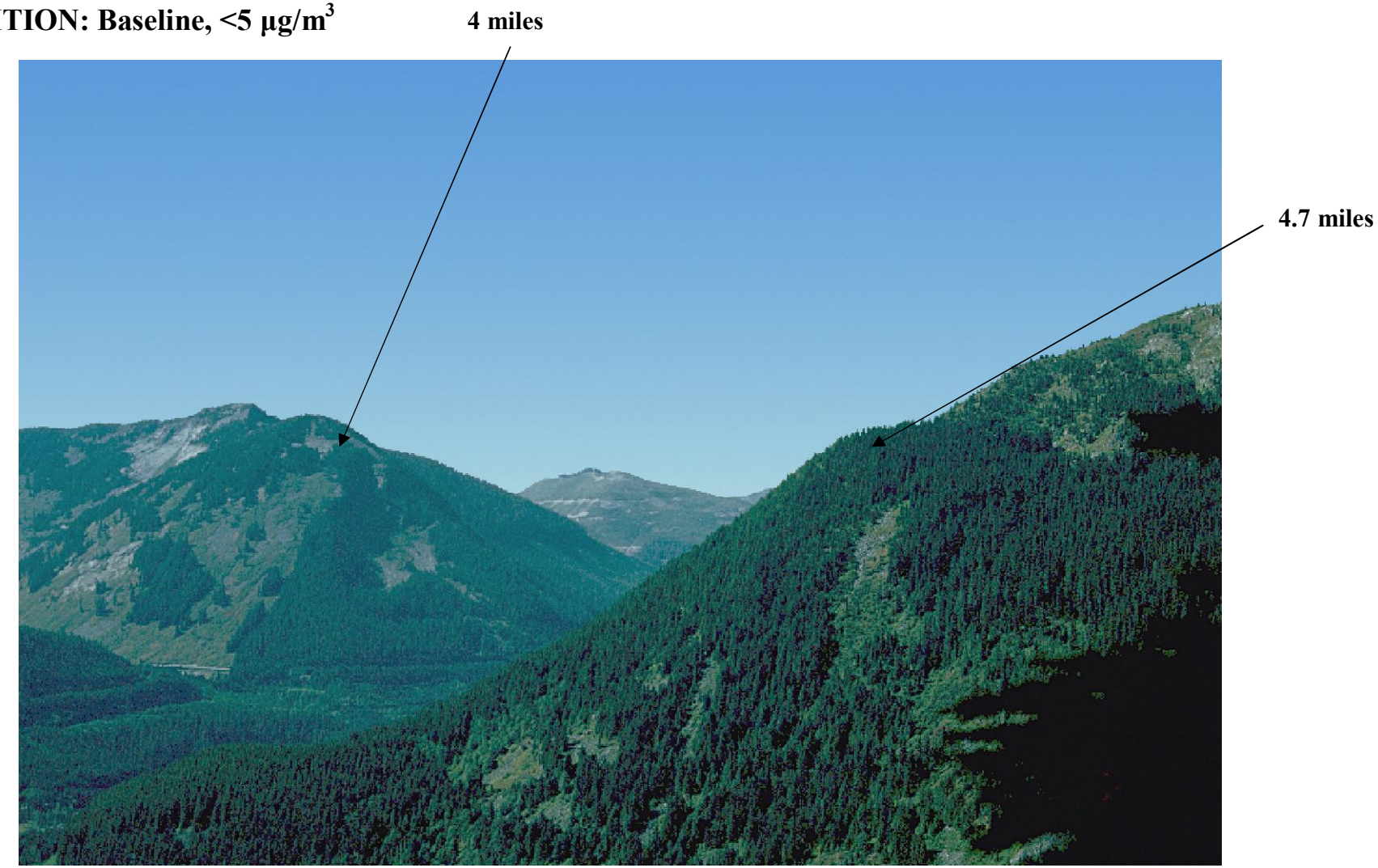
Days of Sampling: 353

Relative humidity ranging between 50% and 90% taken from SeaTac Airport, WA

Constituents of PM represented herein (µg/m^3)		
	Baseline	Elevated
Ammonium Sulfate	0.31	1.84
Ammonium Nitrate	0.1	0.59
Organic Carbon	0.39	-
LAC/Black Carbon	0.16	-
Fine Soil	0.07	0.81
Coarse mass	1.61	3.82

Snoqualmie Pass, WA

CONDITION: Baseline, <5 µg/m^3



PM 2.5	**<5.0 µg/m^3**
Relative Humidity	**50%**
Visual Range	**154.1 miles**

Snoqualmie Pass, WA

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**50%**
Visual Range	**26.6 miles**

Snoqualmie Pass, WA

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**60%**
Visual Range	**25.8 miles**

Snoqualmie Pass, WA

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**70 %**
Visual Range	**25.0 miles**

Snoqualmie Pass, WA

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**80 %**
Visual Range	**23.9 miles**

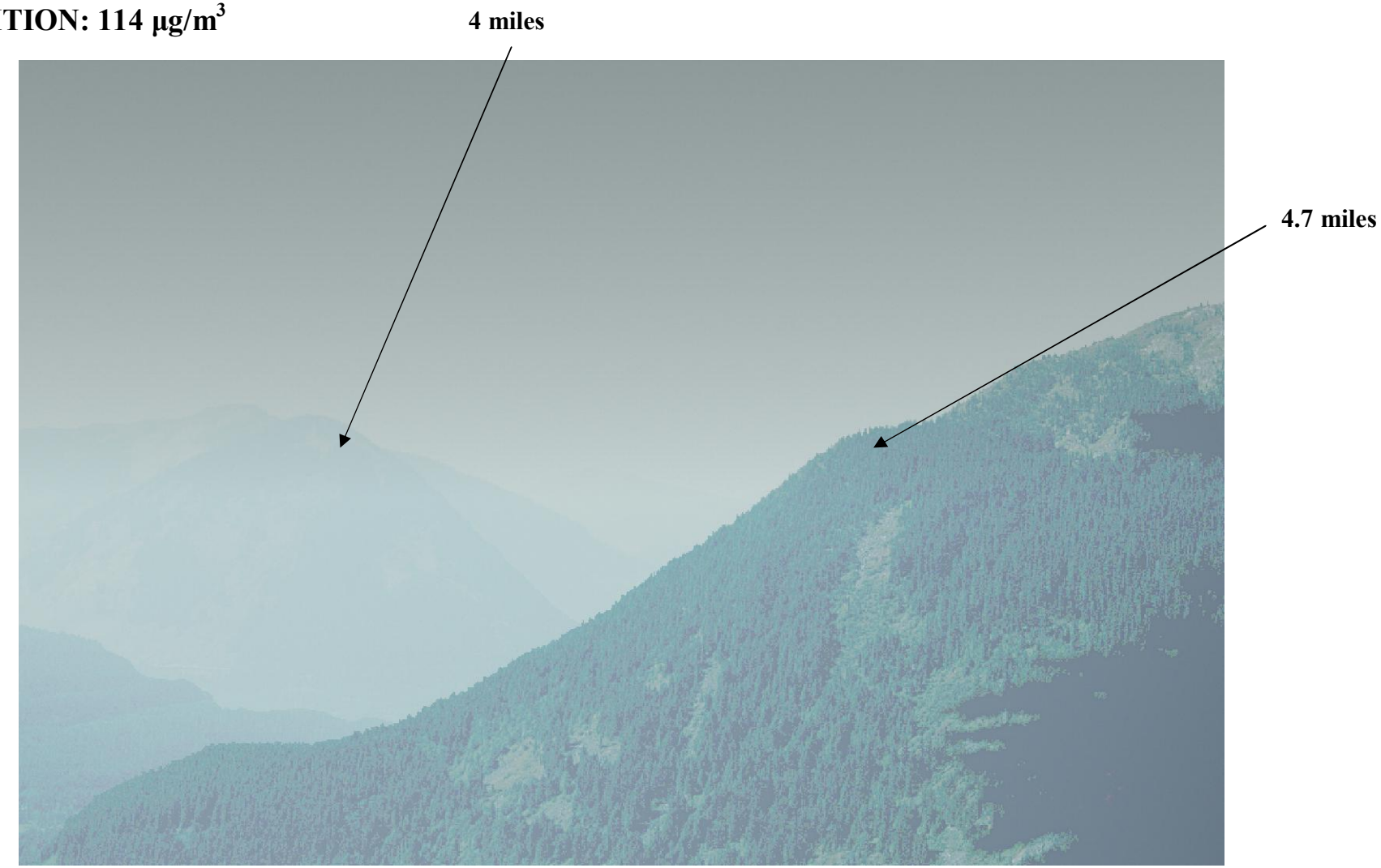
Snoqualmie Pass, WA

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**90 %**
Visual Range	**22.1 miles**

Snoqualmie Pass, WA

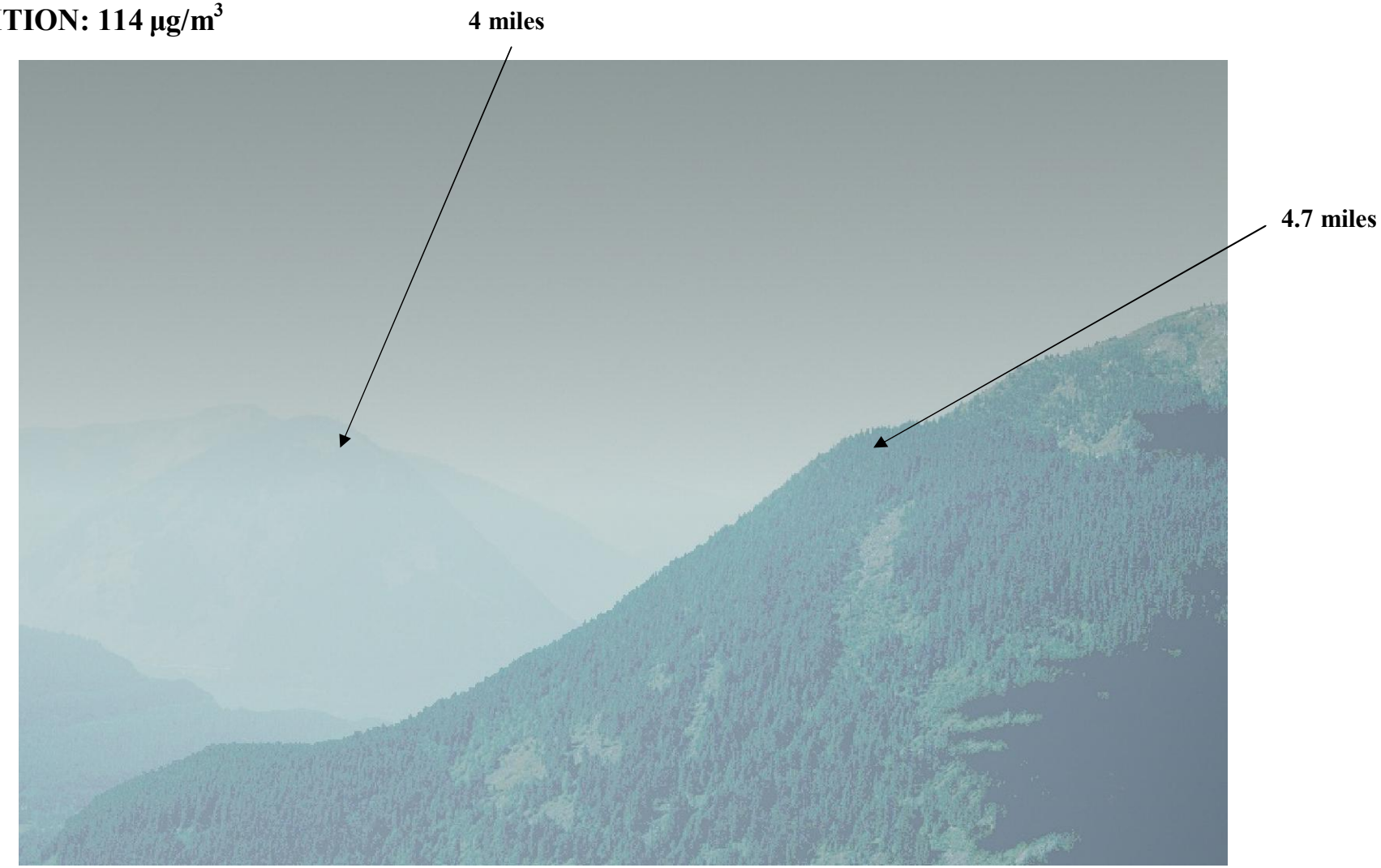
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**50% - 60%**
Visual Range	**4.8 miles**

Snoqualmie Pass, WA

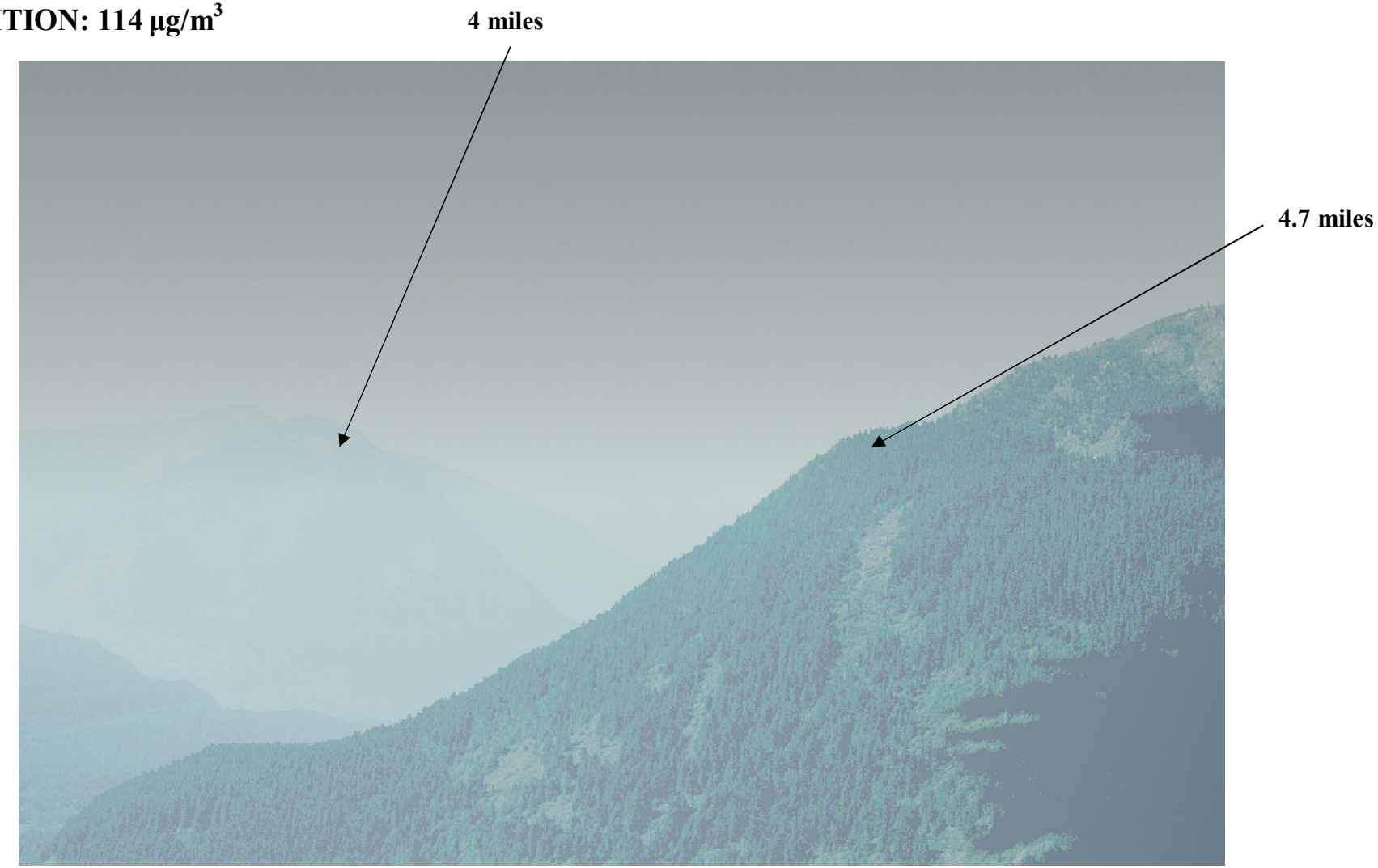
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**70% - 80%**
Visual Range	**4.7 miles**

Snoqualmie Pass, WA

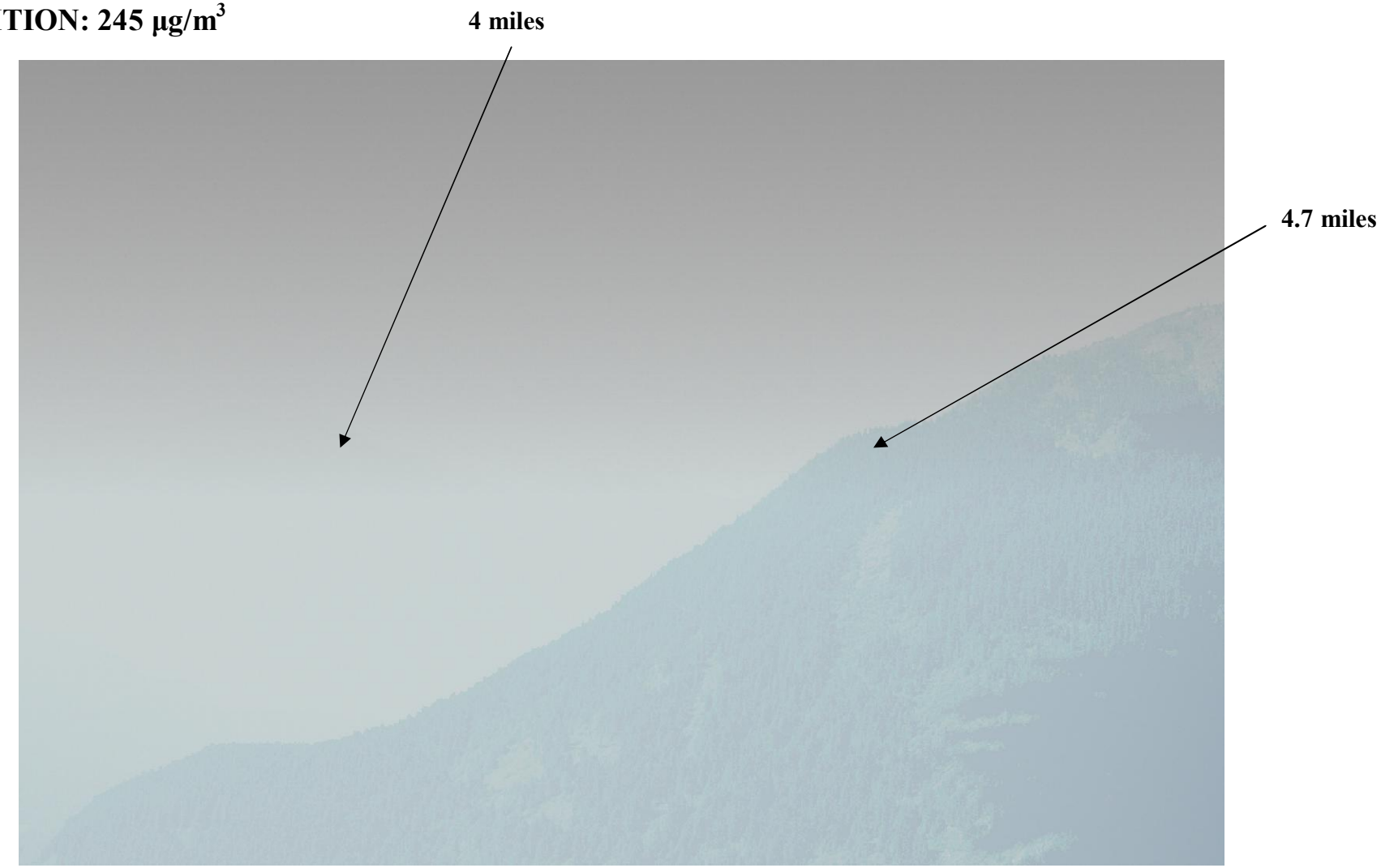
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**90 %**
Visual Range	**4.6 miles**

Snoqualmie Pass, WA

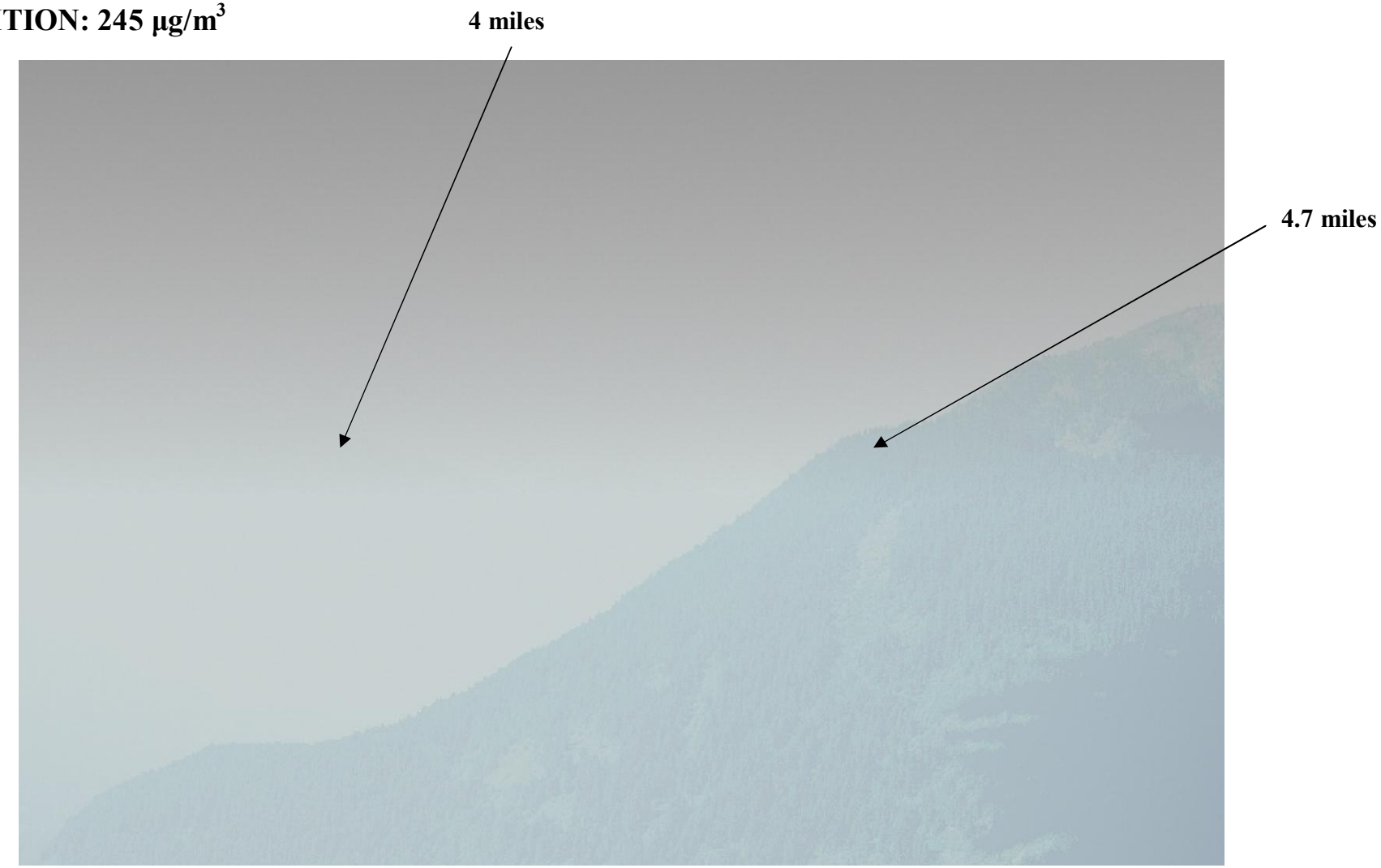
CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**50 %**
Visual Range	**2.3 miles**

Snoqualmie Pass, WA

CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**60% - 90%**
Visual Range	**2.2 miles**

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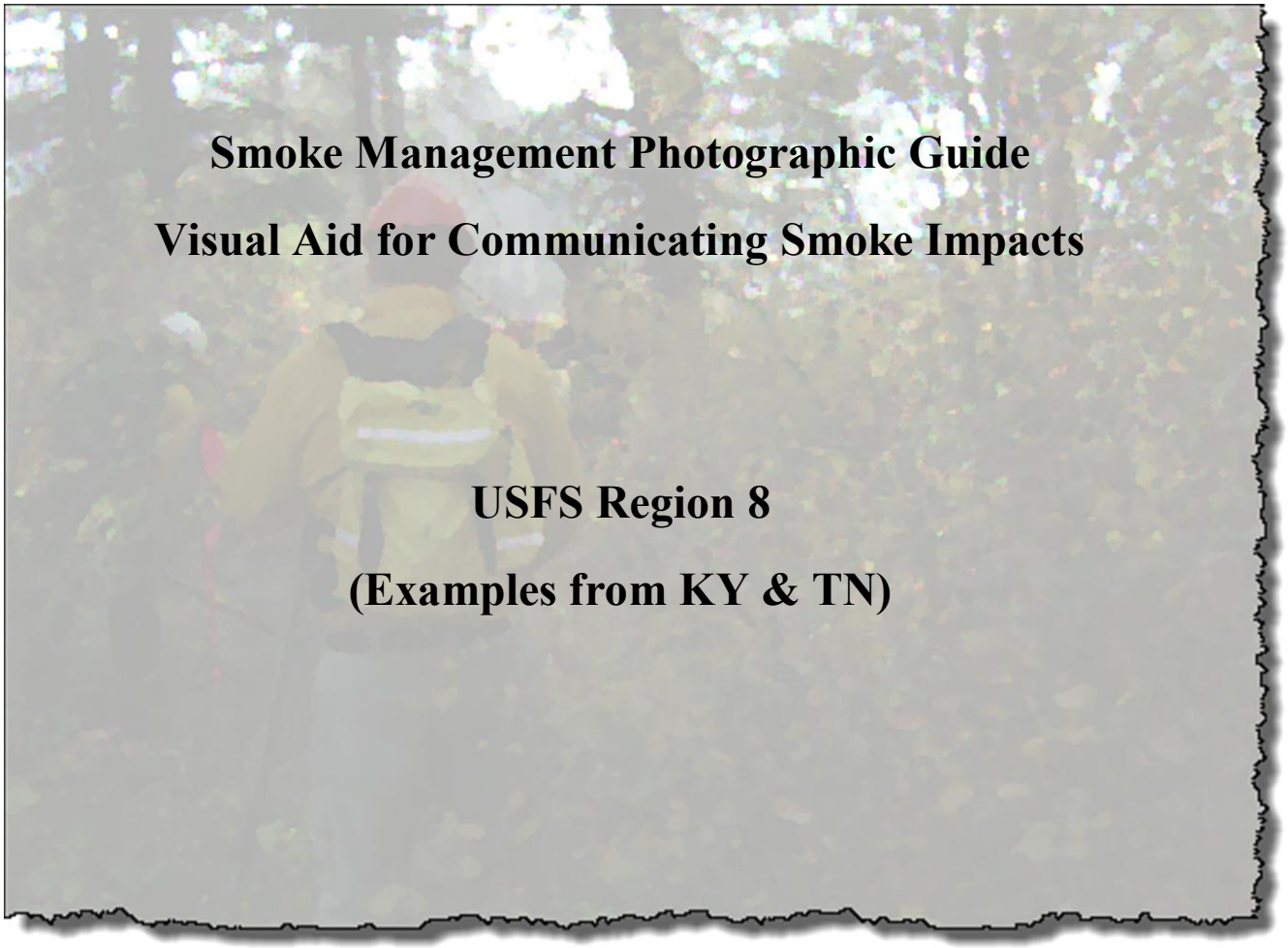


Smoke Management Photographic Guide

Visual Aid for Communicating Smoke Impacts

USFS Region 8

(Examples from KY & TN)

University of Idaho
College of Natural Resources

Development and Scope:
This guide is developed by the University of Idaho College of Natural Resources with images from US National Park and USDA Forest Service locations.

The primary purpose of this guide is to serve as a tool for communicating potential particulate matter (PM 2.5) levels using visual representation. Numerous factors impact visibility; in addition to particulate matter and the presence of ozone (Aherns 2003), visibility is also affected by compounds including ammonium nitrate, ammonium sulfate, and light absorbing carbon (Malm *et al.* 1994), as well as relative humidity (Achtemeier et al. 2001). Existing background levels of visibility also vary across the country (Core 2001). This guide is intended to indicate smoky conditions in USFS Region 8. Due to the complexity of variables, and limitations in the distances perceived by the human eye, visual approximations should be used as indicators, not precise measurement.

Figure 1 The materials in this guide are for estimation purposes only and indented to represent the overall conditions in the highlighted regions.

Methods
To represent visual impacts from smoke in numerous locations across the Unites States this reference guide has been generated using WinHaze imaging software (Air Resource Specialists Inc. 2013). This software package incorporates several years of particulate data from Class I airsheds throughout the continental United States. The program allows for consistent visual representation of airsheds under varying humidity, background pollutant levels and particulate matter (PM) concentrations based on the IMPROVE equation for estimating ambient light extinction coefficients (Hand and Malm 2006). This methodology facilitates consistent representation of smoky conditions while avoiding variations in sun angle and camera placement that can occur using a more traditional method of matching photographs with monitoring data. Mammoth Caves National Park was chosen for this guide based on 1067 days of particulate data incorporated into the visual estimates. To establish an image representing the area free of any smoke-impaired visibility a 'baseline' image was generated in WinHaze using the mean values indicated in the table on the left which total less than 6 $\mu g/m^3$ fine particulate matter and less than 5 $\mu g/m^3$ of coarse particulates.

Constituents of PM represented herein ($\mu g/m^3$)		
	Baseline	Elevated
Ammonium Sulfate	2.64	13.99
Ammonium Nitrate	0.81	0.65
Organic Carbon	1.38	-
LAC/Black Carbon	0.29	-
Fine Soil	0.31	1.13
Coarse mass	3.16	6.26

Visual impairment from smoke is simulated first by establishing constant values for the constituent of PM unlikely to change as the result of smoke from fires. 'Elevated' values for ammonium sulfate, ammonium nitrate, fine soil, and coarse mass were determined by using values recorded for the 20% worst visibility days. Organic carbon and Black carbon are then increased to reflect increasing concentrations of smoke, as this carbon

composes nearly 75% of the emissions from forest fires (Andreae & Merlet 2001). The ratio of organic carbon to black carbon will be represented by a 15.4/1 ratio based on estimates for wildland fire in non-tropical forests in a comprehensive review by Andreae & Merlet (2001).

Because relative humidity (RH) impacts visibility and changes throughout the fire season, a range of different RH levels is represented based on morning and afternoon averages. Data for these averages is taken from Louisville, KY (NOAA 2013). Values between the months of May and September were chosen to represent the relative humidity levels most likely to be present during the wildland fire season. For additional reference examples of Great Smoky Mountains National Park in TN are also included herein.

This guide represents short-term (1-3 hour) exposure pollutant levels as presented the Wildfire Smoke, A Guide for Public Health Officials (Lipset *et al.* 2008). The categories ('Good', 'Moderate', etc.) use terminology based on the EPA's Air Quality Index (US EPA, 2009). Due to the difficulty of distinguishing a fine scale measurement such as particulate concentration by using eyesight alone, three values were chosen, each in the mid-range of a health effect index category (*below*).

EPA Values for PM		Concentrations
AQI Value	Actions to protect your health from particle pollution	PM2.5 or PM10 Levels ($\mu g/m^3$) 1 to 3 hour average
Good (0-50)	None	0-38
Moderate (51-100)	Unusually sensitive people should consider reducing prolonged or heavy exertion.	39-88
Unhealthy for Sensitive Groups 101-150	The following groups should reduce prolonged or heavy outdoor exertion: -People with heart or lung disease -Children and older adults Everyone else should limit prolonged or heavy exertion	89-138
Unhealthy (151-200)	The following groups should avoid all physical outdoors: -People with heart or lung disease -Children and older adults Everyone else should avoid prolonged or heavy exertion	139-351
Very Unhealthy (201-300)	The following groups should remain indoors and keep activity levels low: -People with heart or lung disease -Children and older adults Everyone else should avoid all physical activity outdoors	352-526+

19 $\mu g/m^3$

114 $\mu g/m^3$

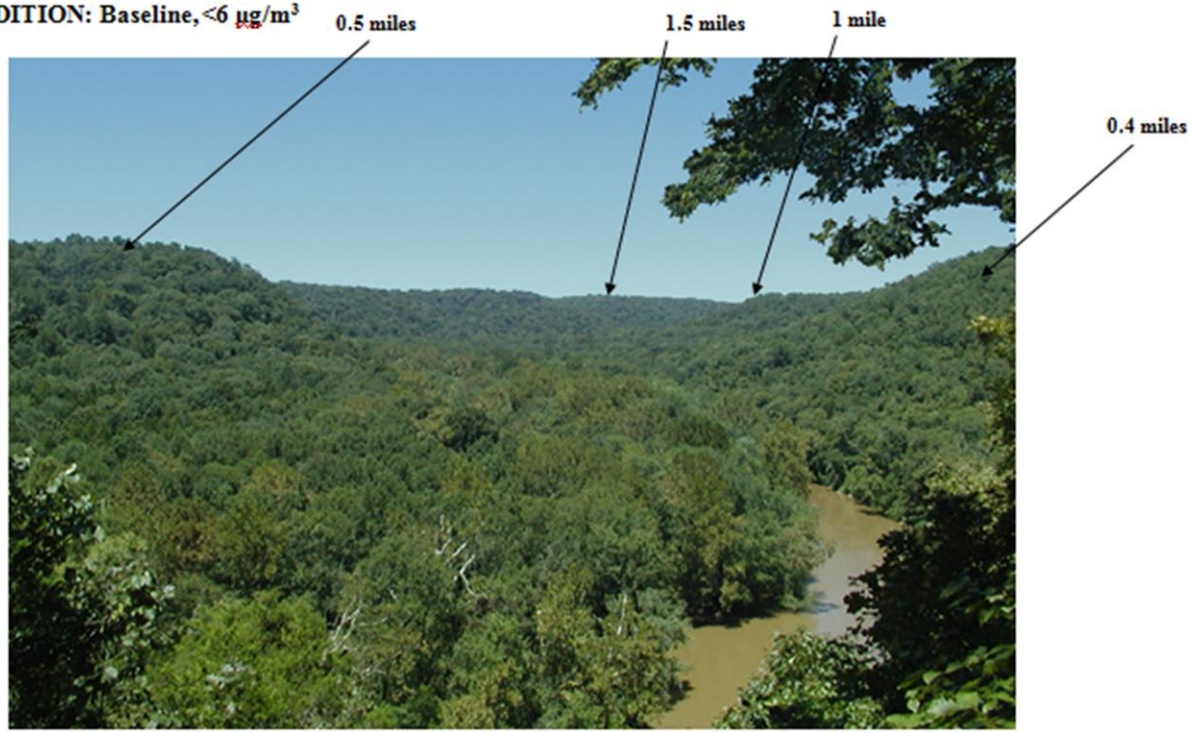
245 $\mu g/m^3$

Using this guide:

To use this guide to represent particulate matter, compare your line of site with landmarks similar distances as those depicted here-in. When making this comparison, face away from the sun. Use points on the landscape of known distances that you are familiar with. Several examples of the same concentration are represented with varying relative humilities based on what is likely to be encountered during the fire season.

MAMMOTH CAVES NATIONAL PARK, KY

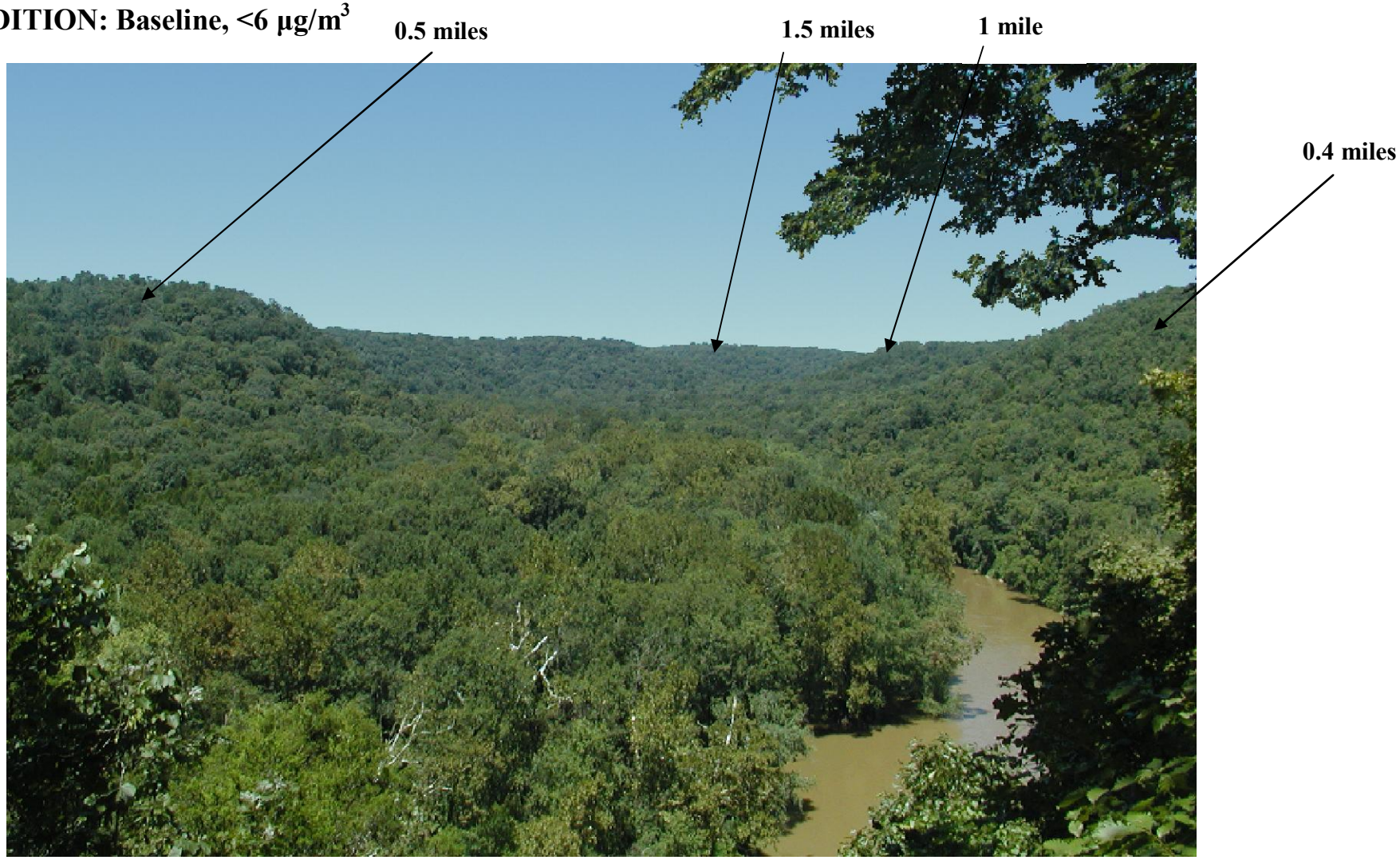
CONDITION: Baseline, <6 µg/m³



PM2.5	<6.0 µg/m³
Relative Humidity	40%
Visual Range	85.7 miles

MAMMOTH CAVES NATIONAL PARK, KY

CONDITION: Baseline, <6 µg/m^3



PM 2.5	**<6.0 µg/m^3**
Relative Humidity	**40%**
Visual Range	**76.4 miles**

MAMMOTH CAVES NATIONAL PARK, KY

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**40%**
Visual Range	**32.0 miles**

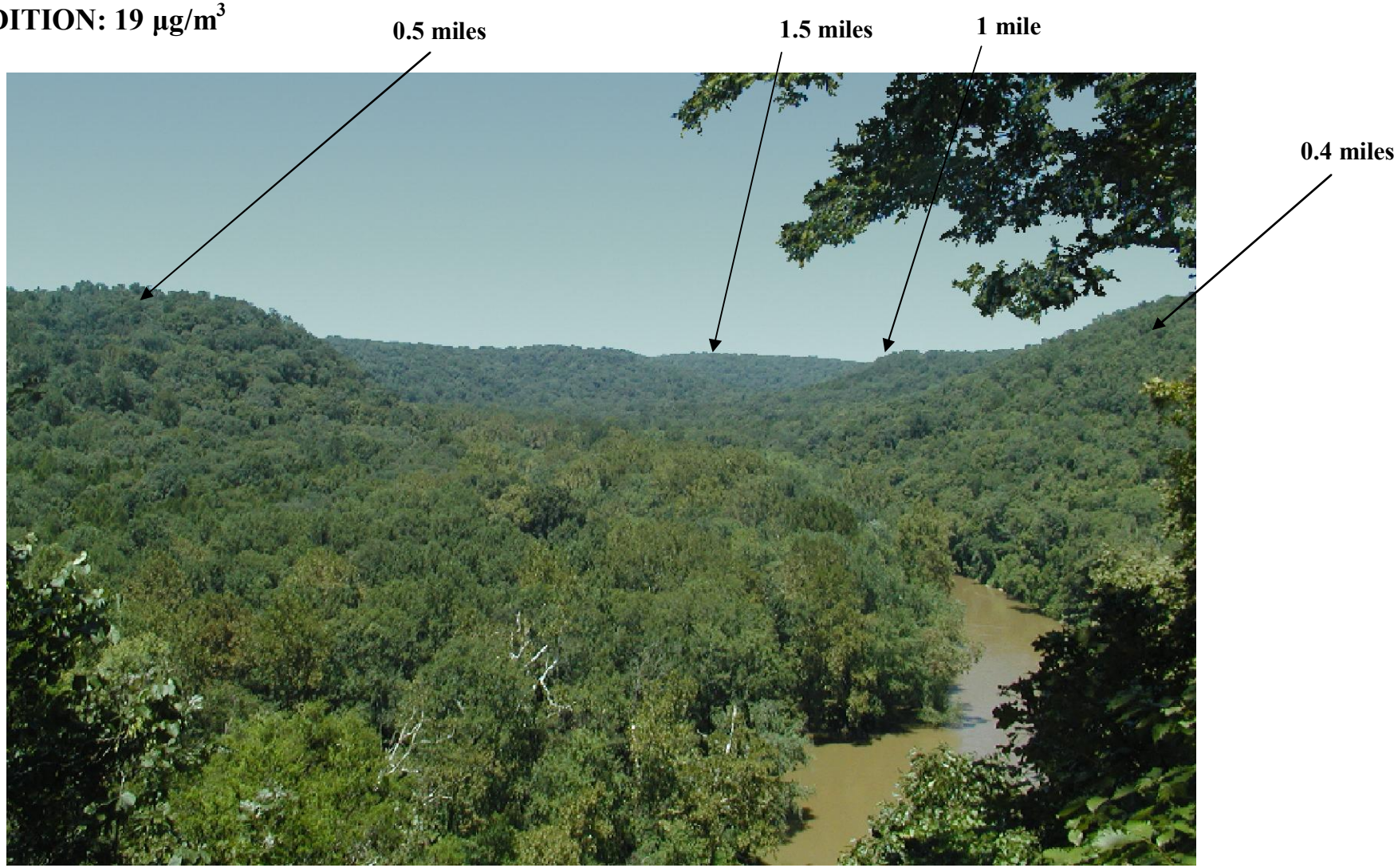
MAMMOTH CAVES NATIONAL PARK, KY

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**50%**
Visual Range	**28.0 miles**

MAMMOTH CAVES NATIONAL PARK, KY

CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**60%**
Visual Range	**23.9 miles**

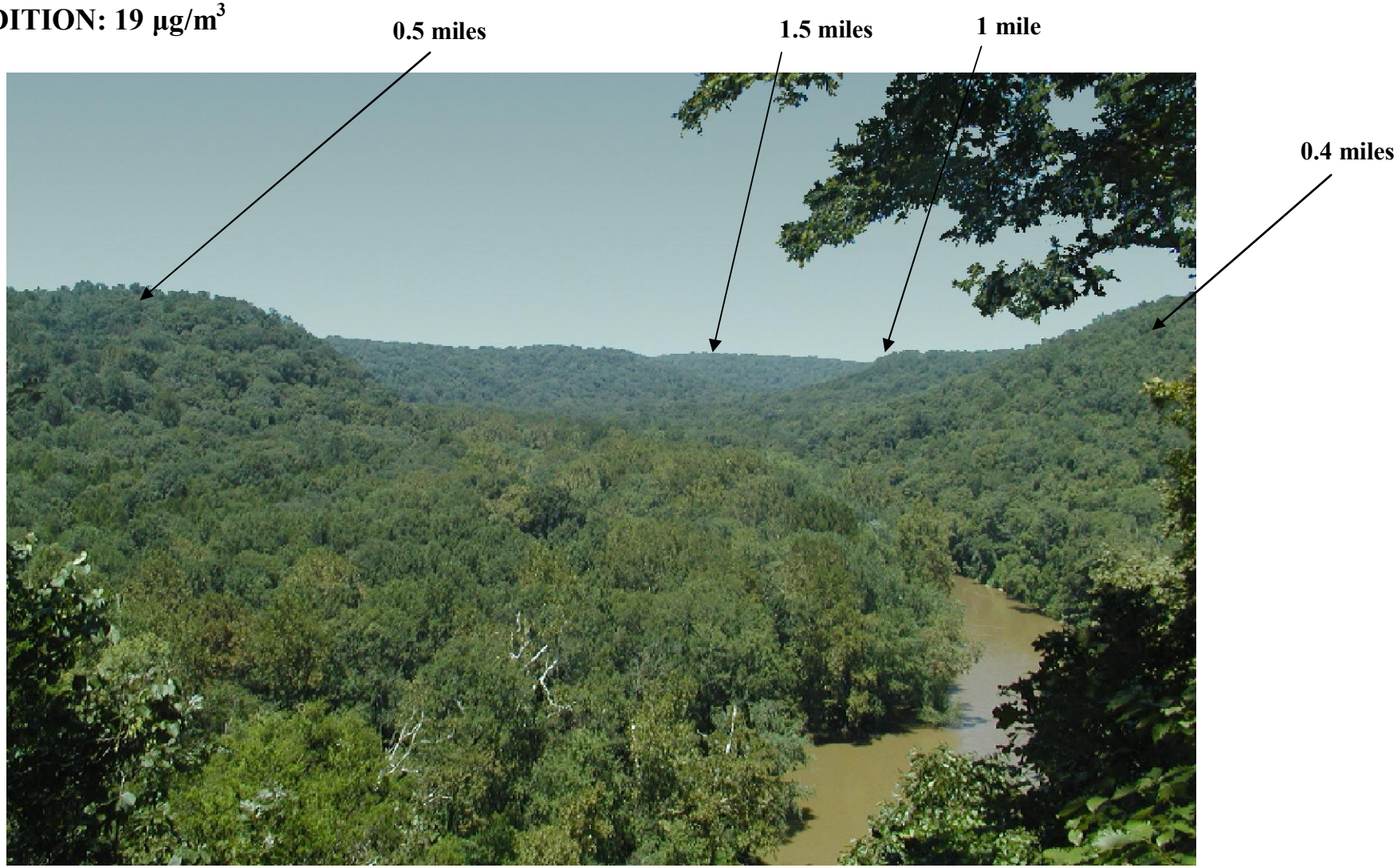
MAMMOTH CAVES NATIONAL PARK, KY

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**70%**
Visual Range	**19.9 miles**

MAMMOTH CAVES NATIONAL PARK, KY

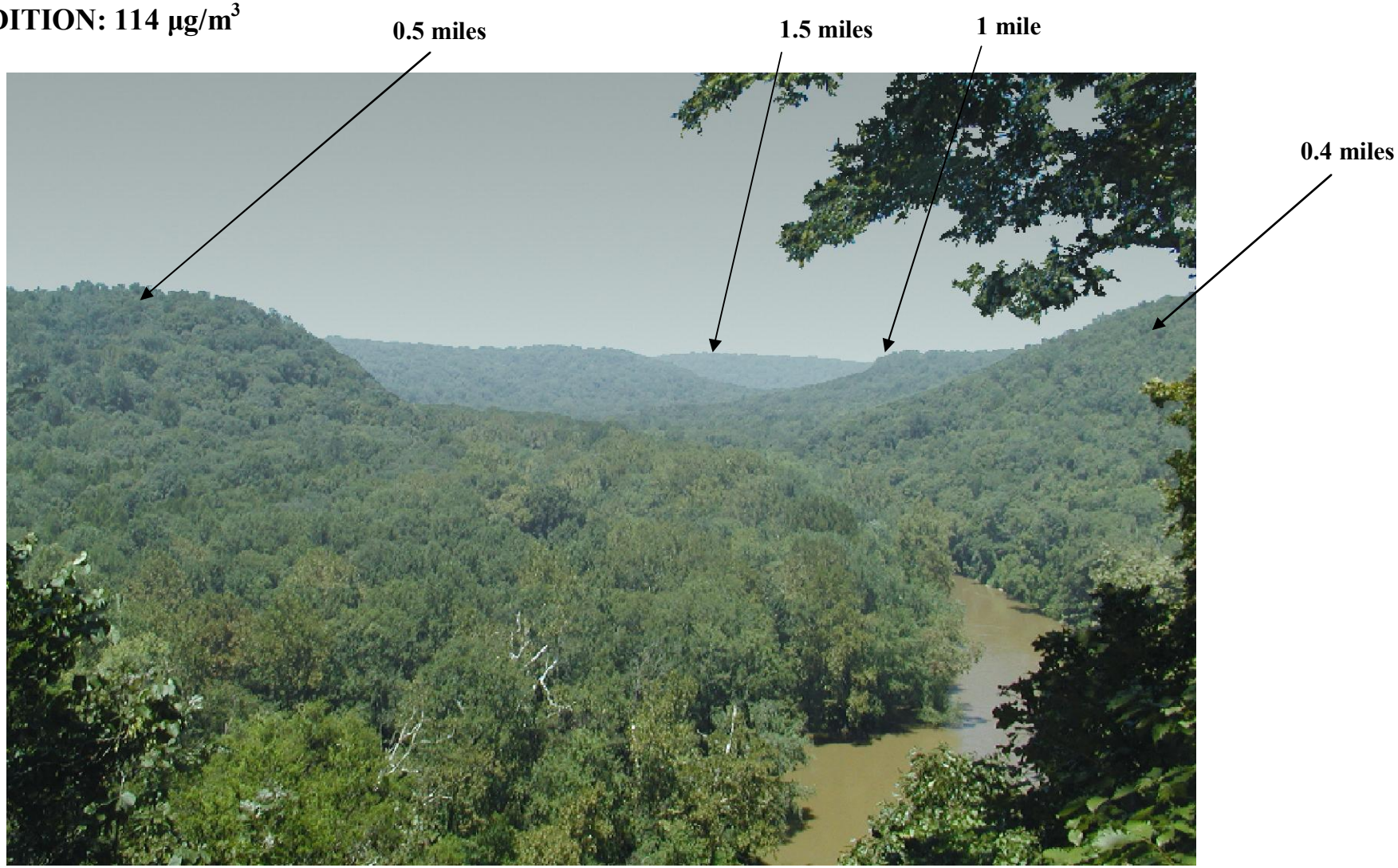
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**80%**
Visual Range	**16.4 miles**

MAMMOTH CAVES NATIONAL PARK, KY

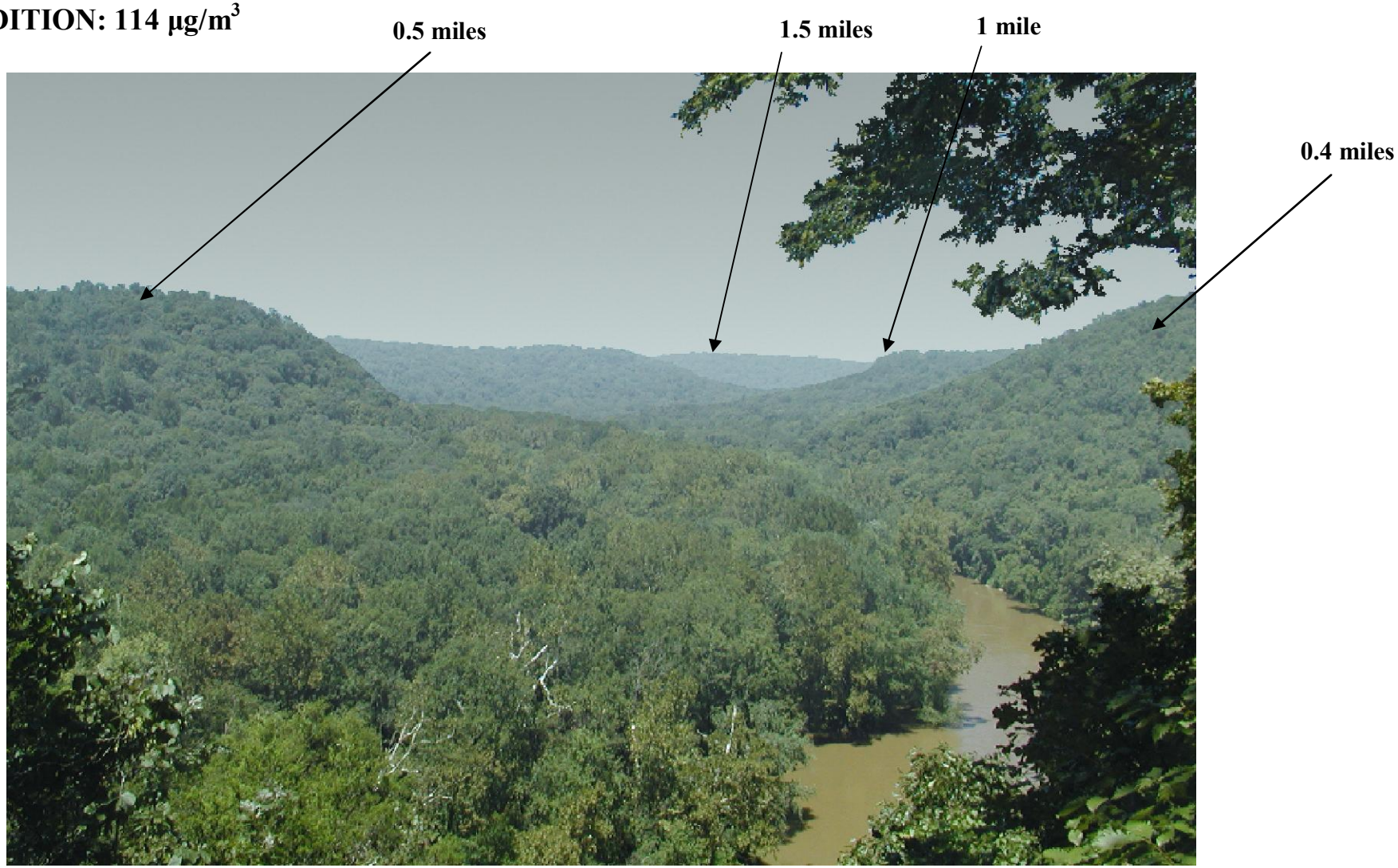
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**40%**
Visual Range	**5.0 miles**

MAMMOTH CAVES NATIONAL PARK, KY

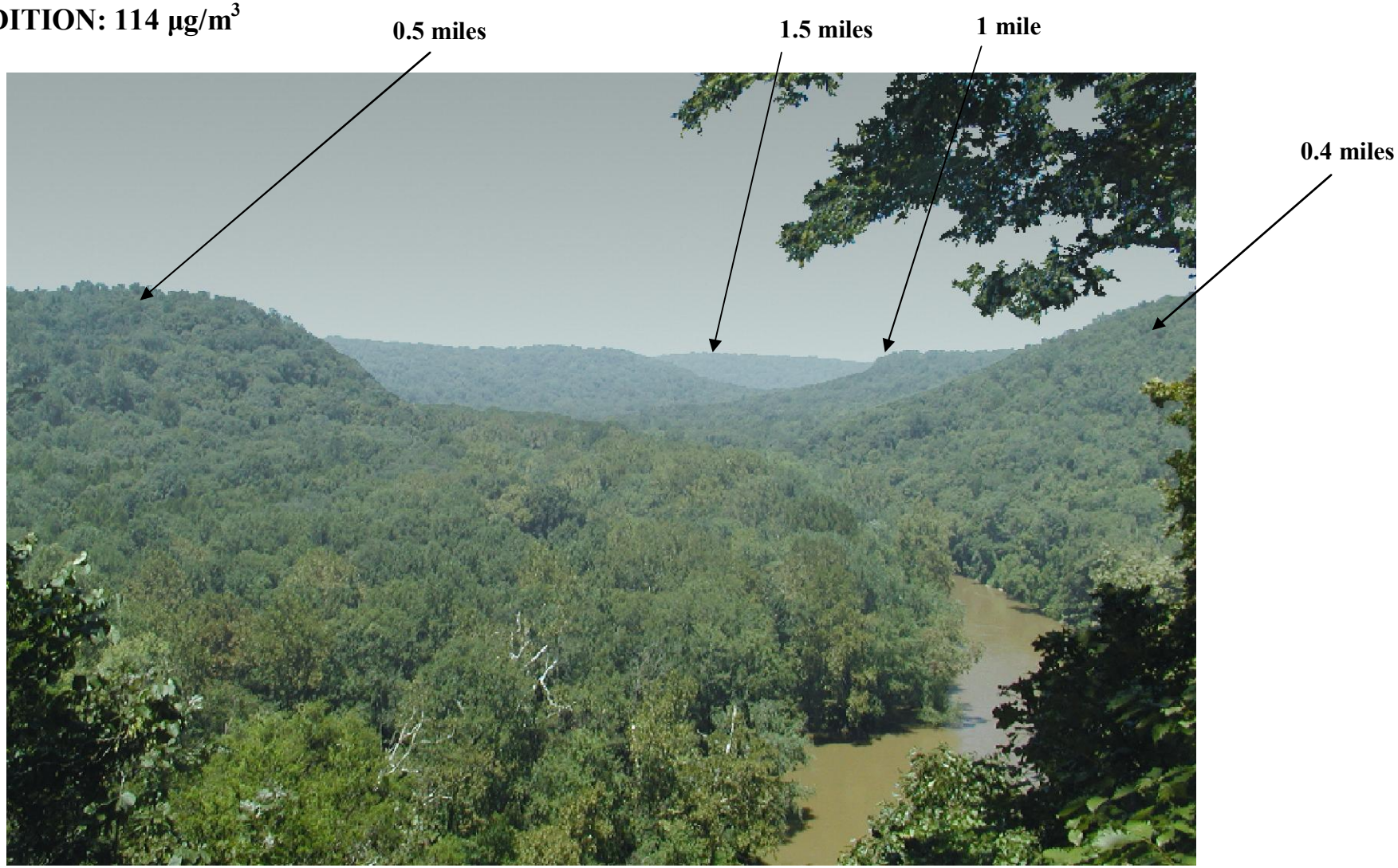
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**50%**
Visual Range	**4.8 miles**

MAMMOTH CAVES NATIONAL PARK, KY

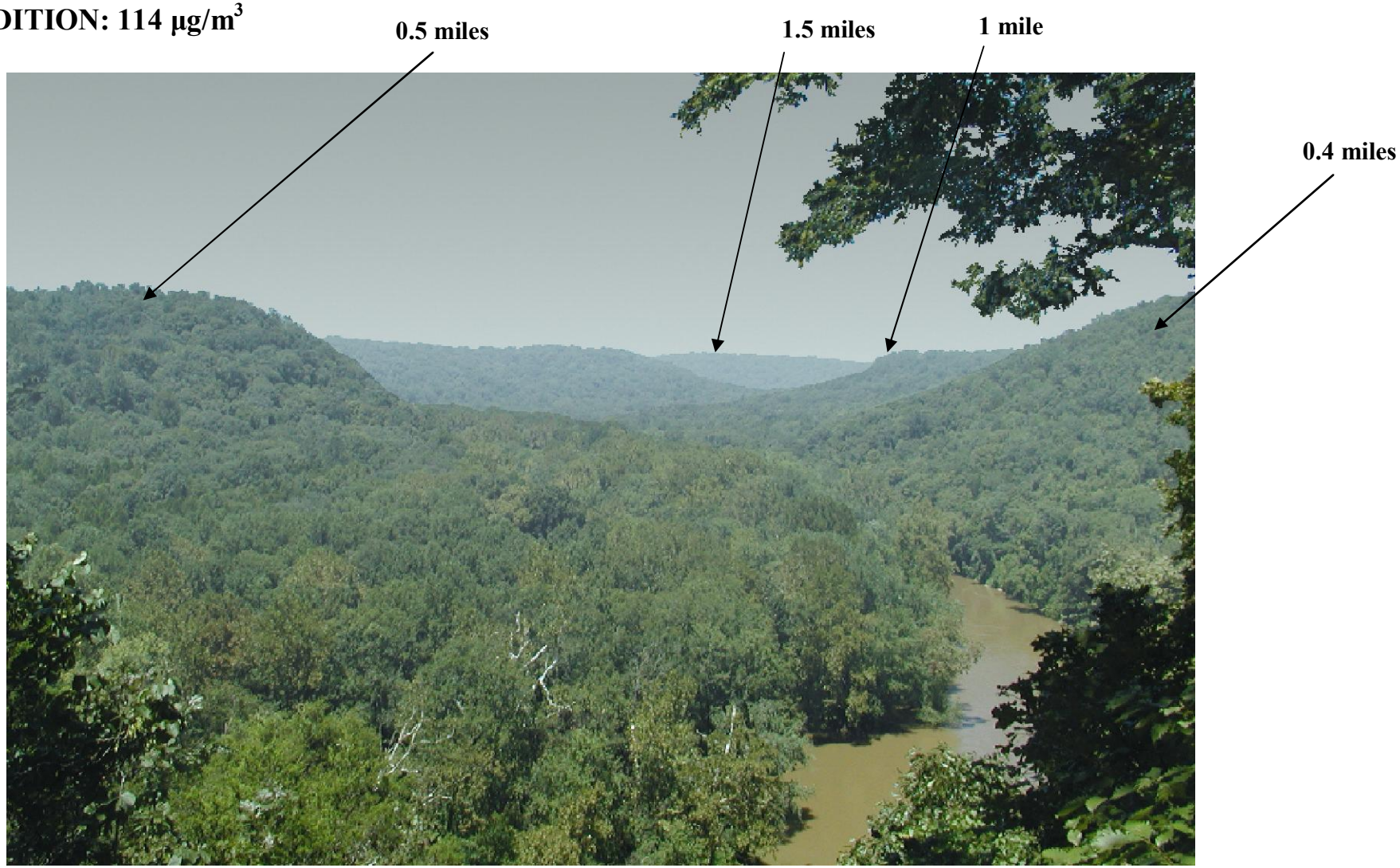
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**60%**
Visual Range	**4.7 miles**

MAMMOTH CAVES NATIONAL PARK, KY

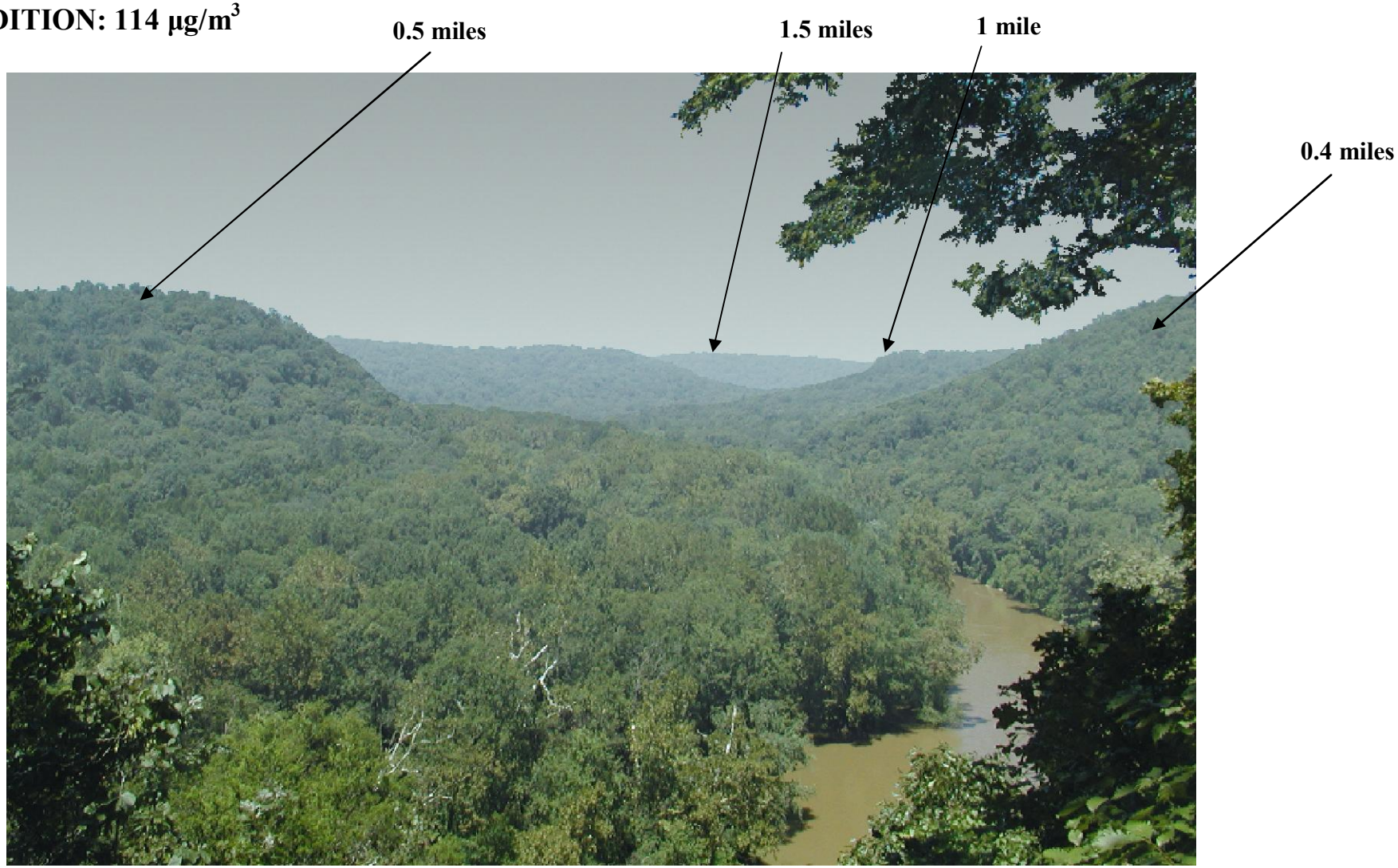
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**70%**
Visual Range	**4.5 miles**

MAMMOTH CAVES NATIONAL PARK, KY

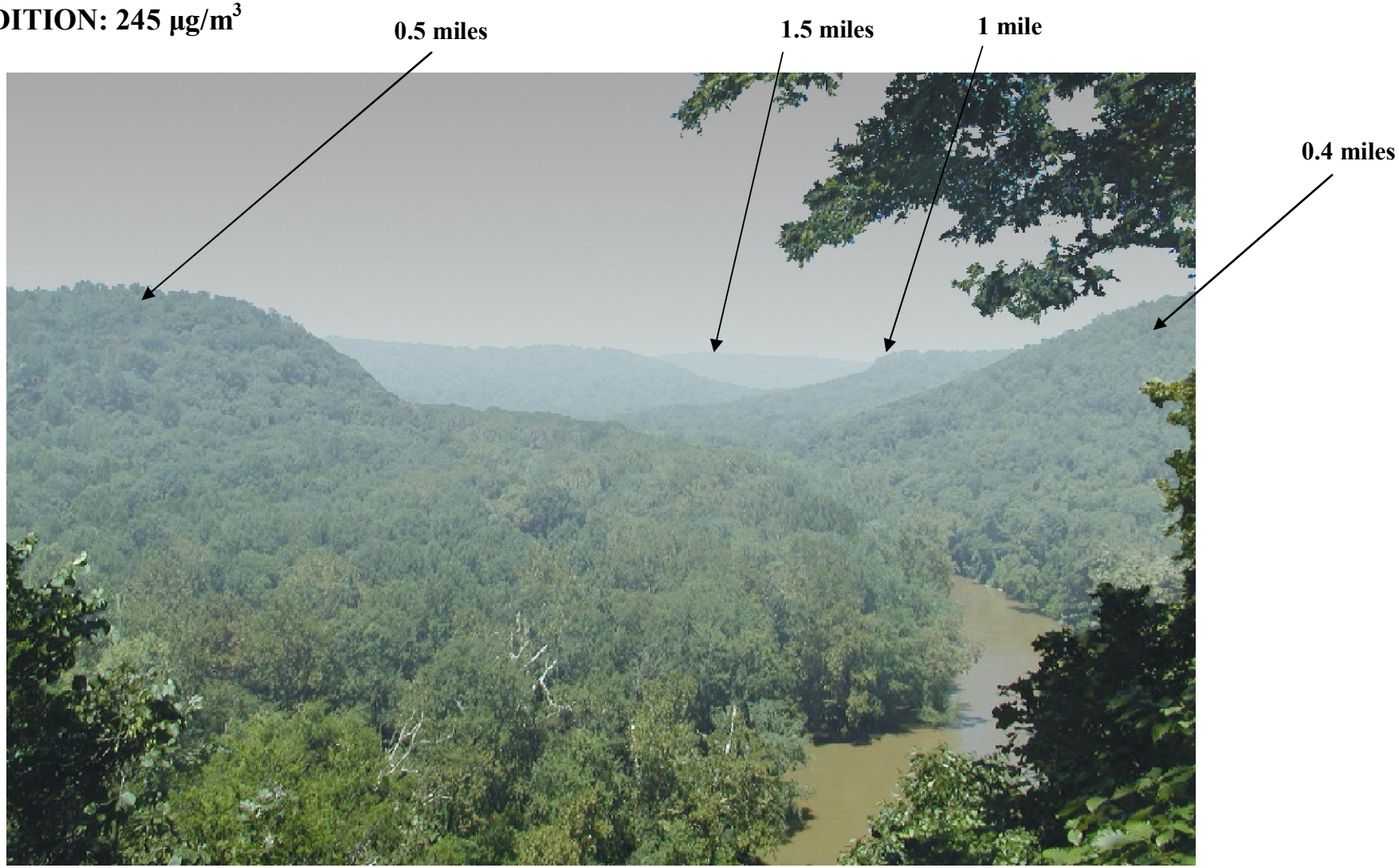
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**80%**
Visual Range	**4.3 miles**

MAMMOTH CAVES NATIONAL PARK, KY

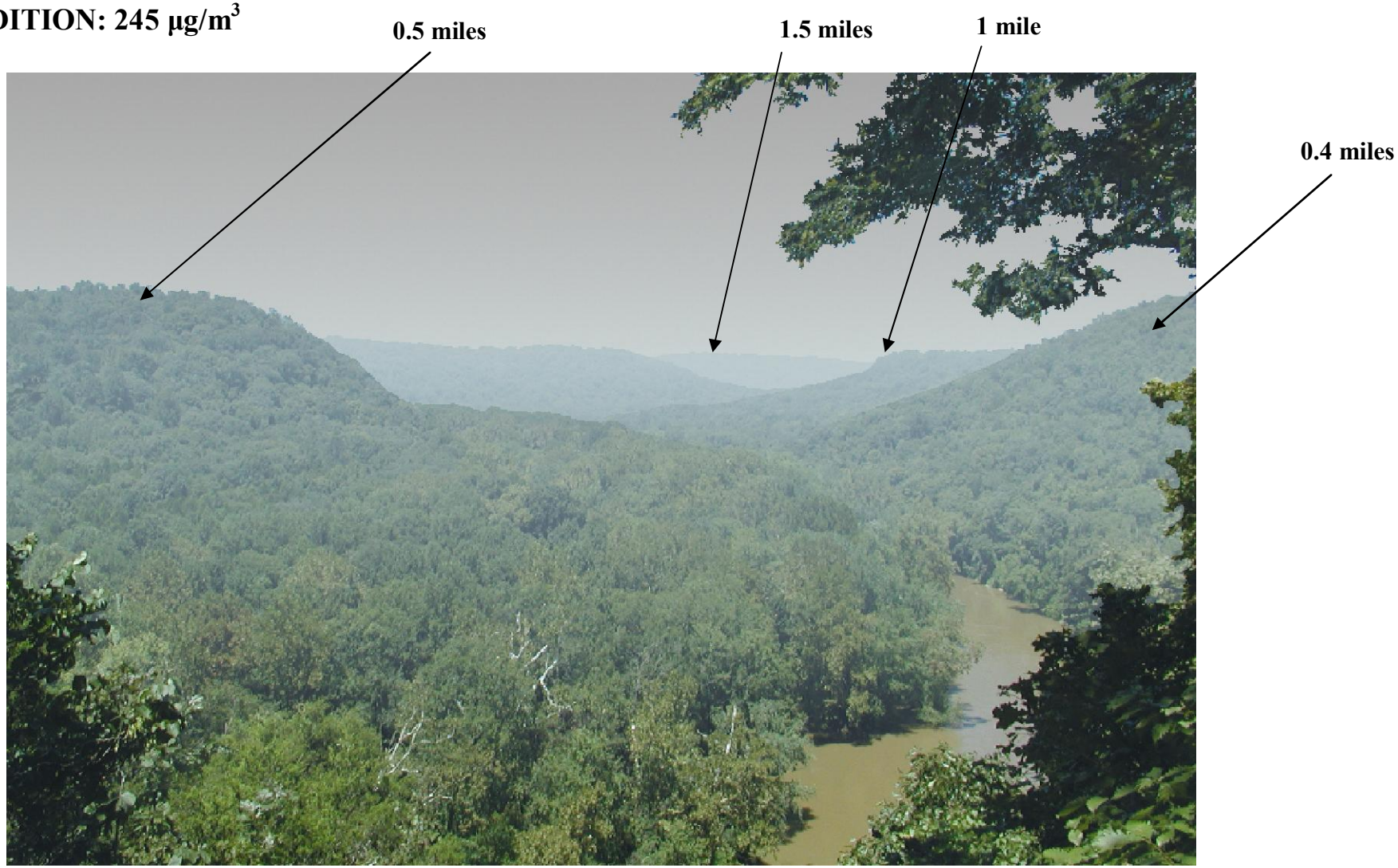
CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**40% - 50%**
Visual Range	**2.3 miles**

MAMMOTH CAVES NATIONAL PARK, KY

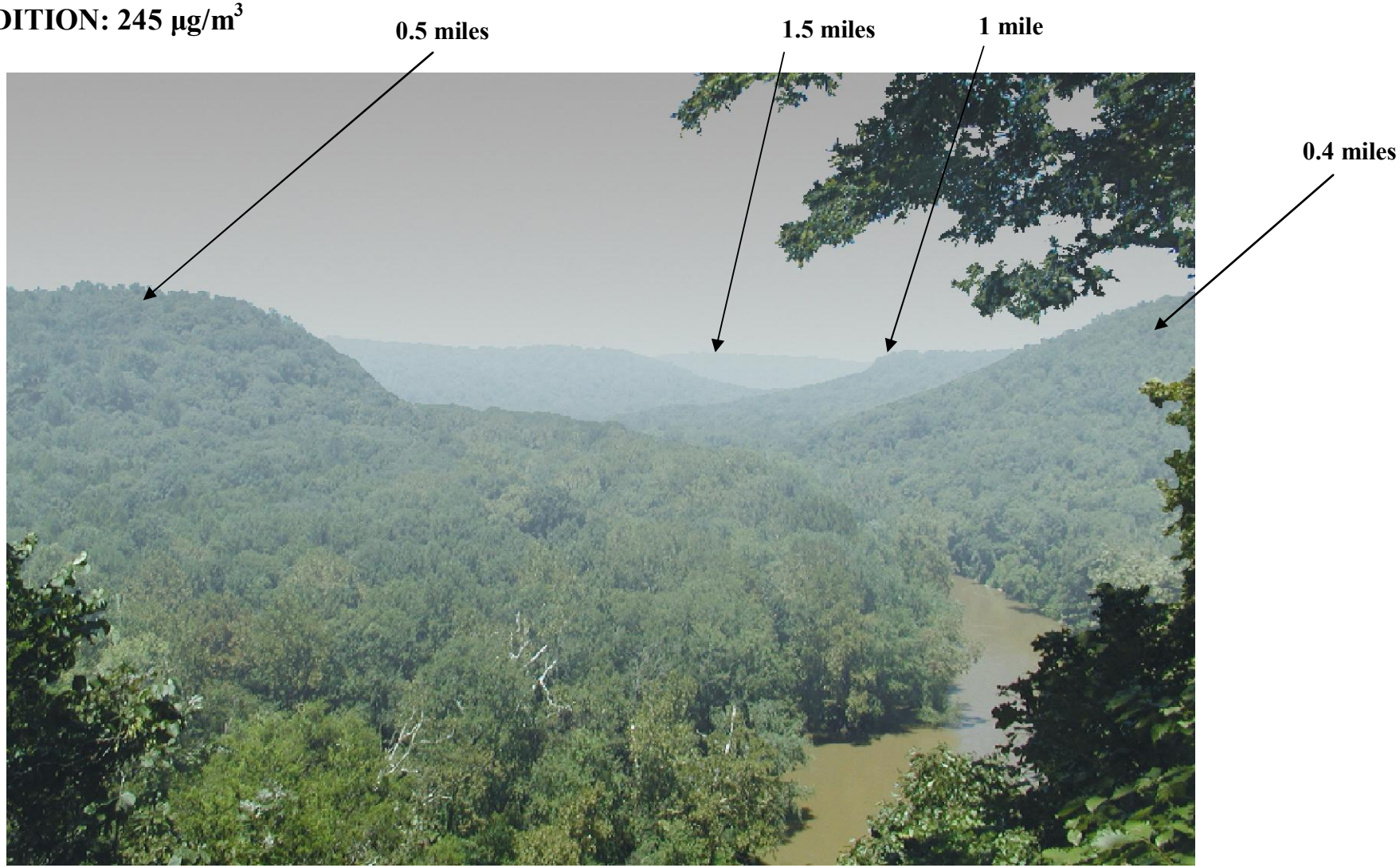
CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**60% to 70%**
Visual Range	**2.2 miles**

MAMMOTH CAVES NATIONAL PARK, KY

CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**80 %**
Visual Range	**2.1 miles**

GREAT SMOKY MOUNTAINS NATIONAL PARK, TN

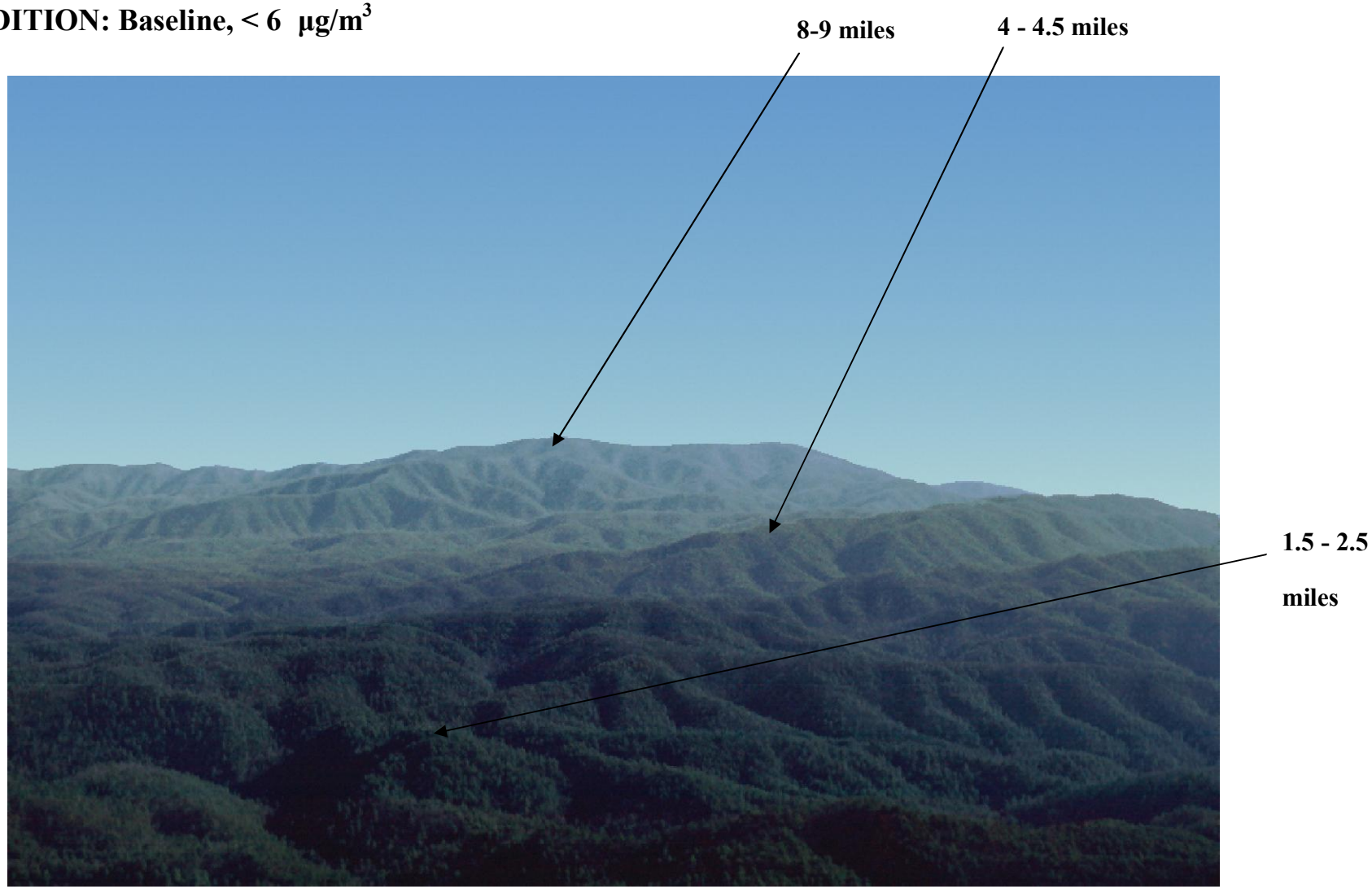
Days of Sampling: 935

Relative humidity ranging between 40% and 80% taken from Knoxville, TN

Constituents of PM represented herein (µg/m^3)		
	Baseline	Elevated
Ammonium Sulfate	2.06	13.97
Ammonium Nitrate	0.36	0.31
Organic Carbon	1.29	-
LAC/Black Carbon	0.31	-
Fine Soil	0.21	1.03
Coarse mass	4.01	7.23

GREAT SMOKY MOUNTAINS N.P., TN

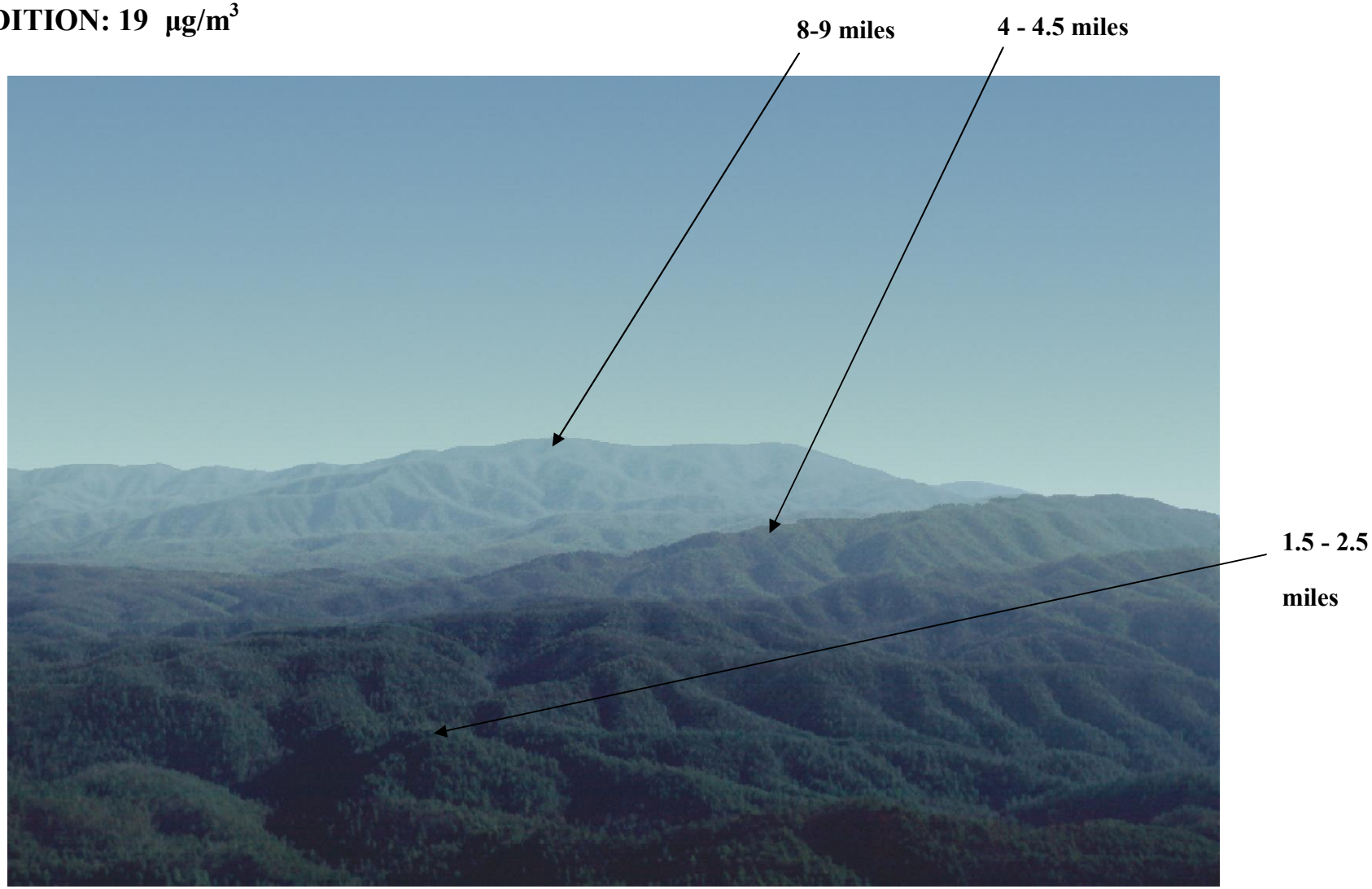
CONDITION: Baseline, < 6 µg/m^3



PM 2.5	**< 6 µg/m^3**
Relative Humidity	**40%**
Visual Range	**85.1 miles**

GREAT SMOKY MOUNTAINS N.P., TN

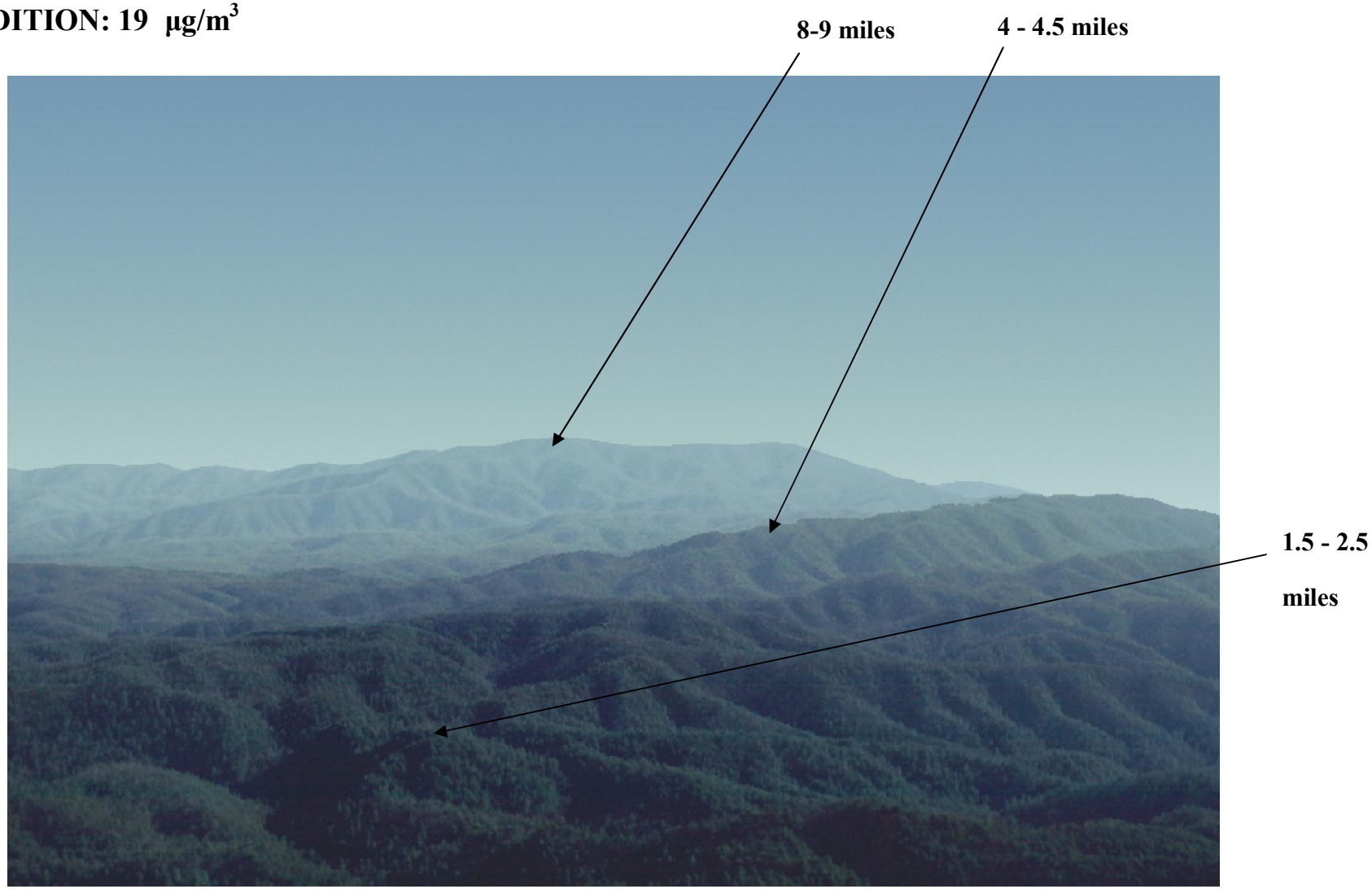
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**40%**
Visual Range	**31.4 miles**

GREAT SMOKY MOUNTAINS N.P., TN

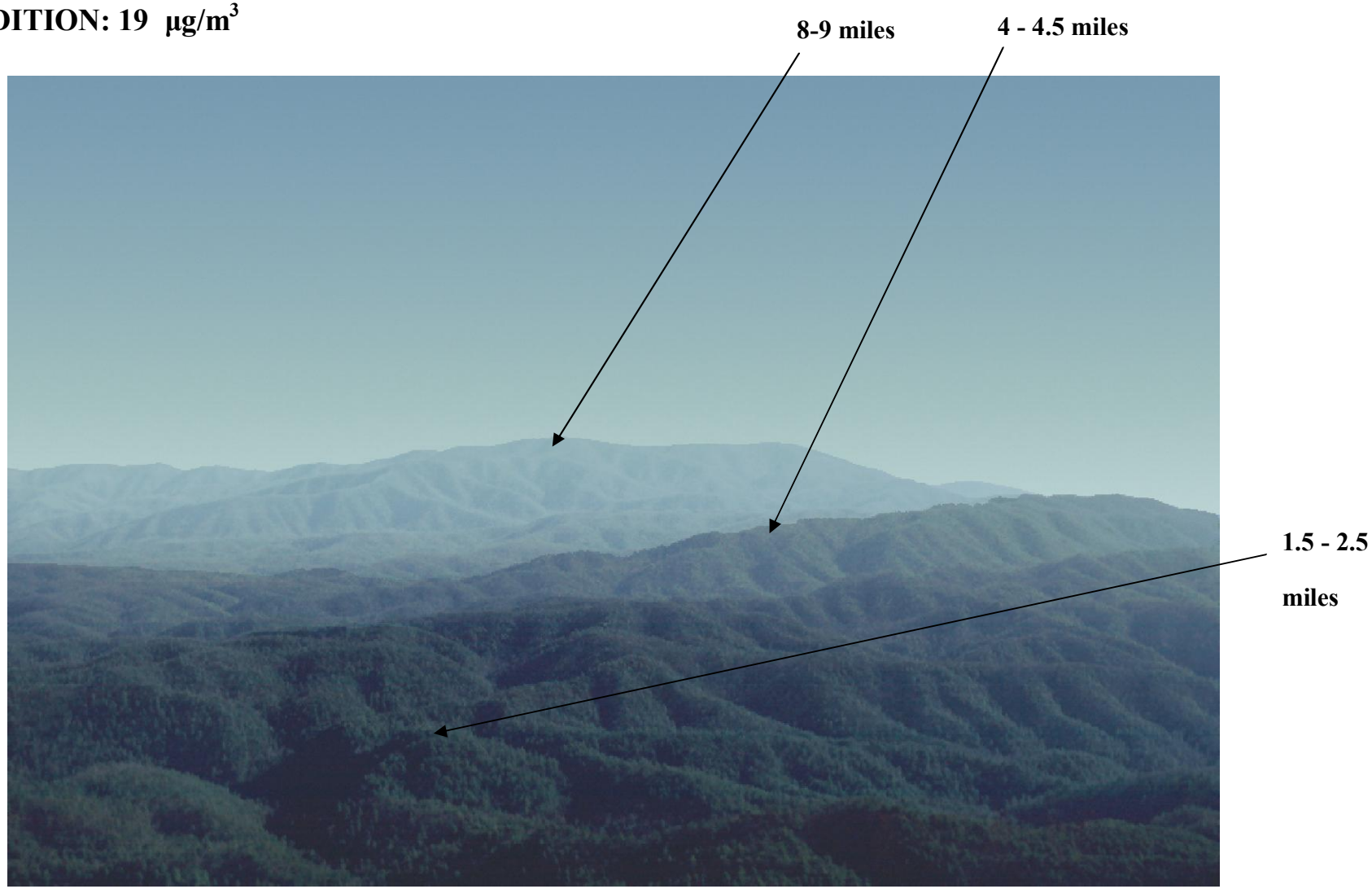
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**50%**
Visual Range	**27.6 miles**

GREAT SMOKY MOUNTAINS N.P., TN

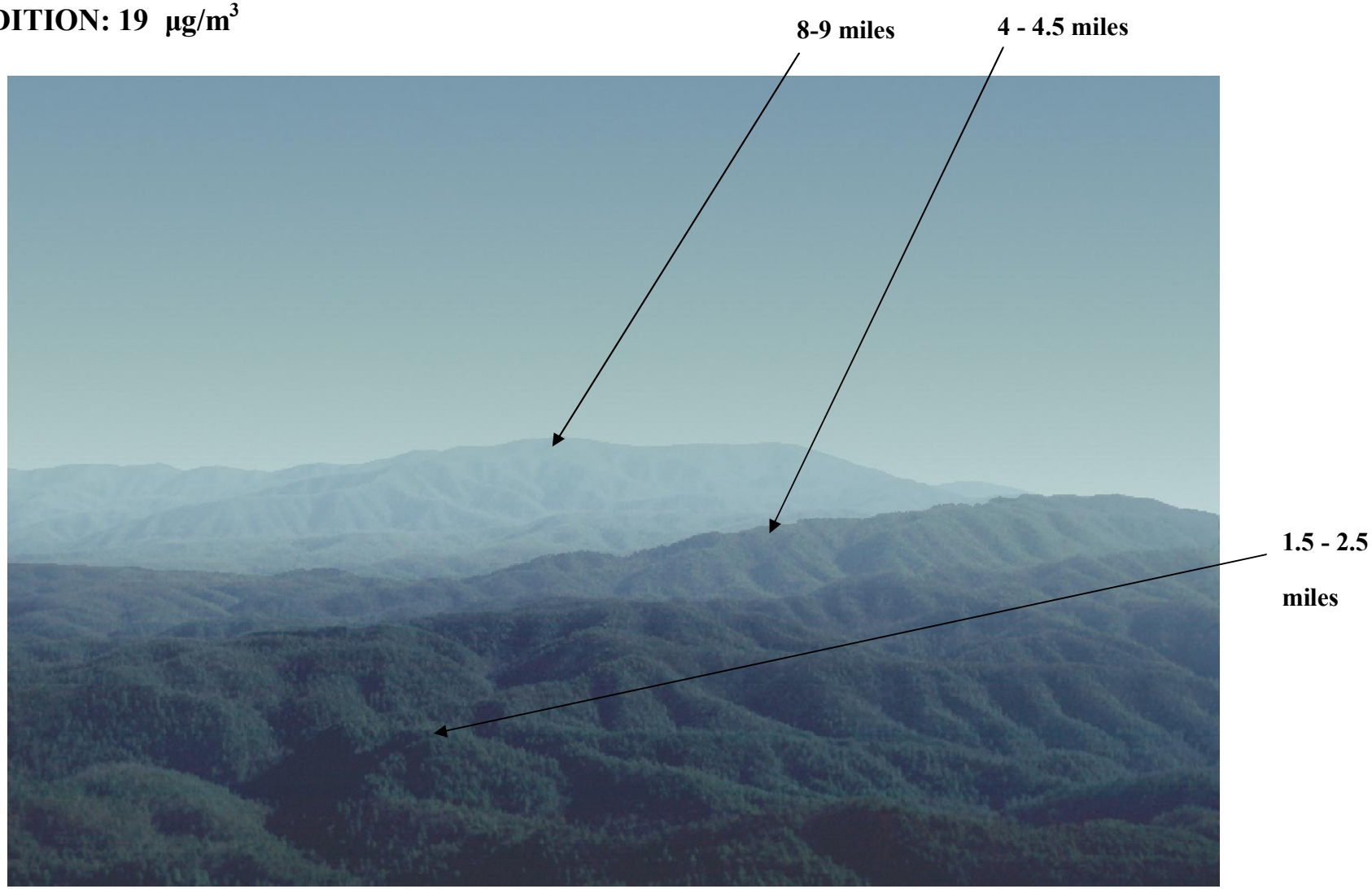
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**60%**
Visual Range	**23.7 miles**

GREAT SMOKY MOUNTAINS N.P., TN

CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**70%**
Visual Range	**19.9 miles**

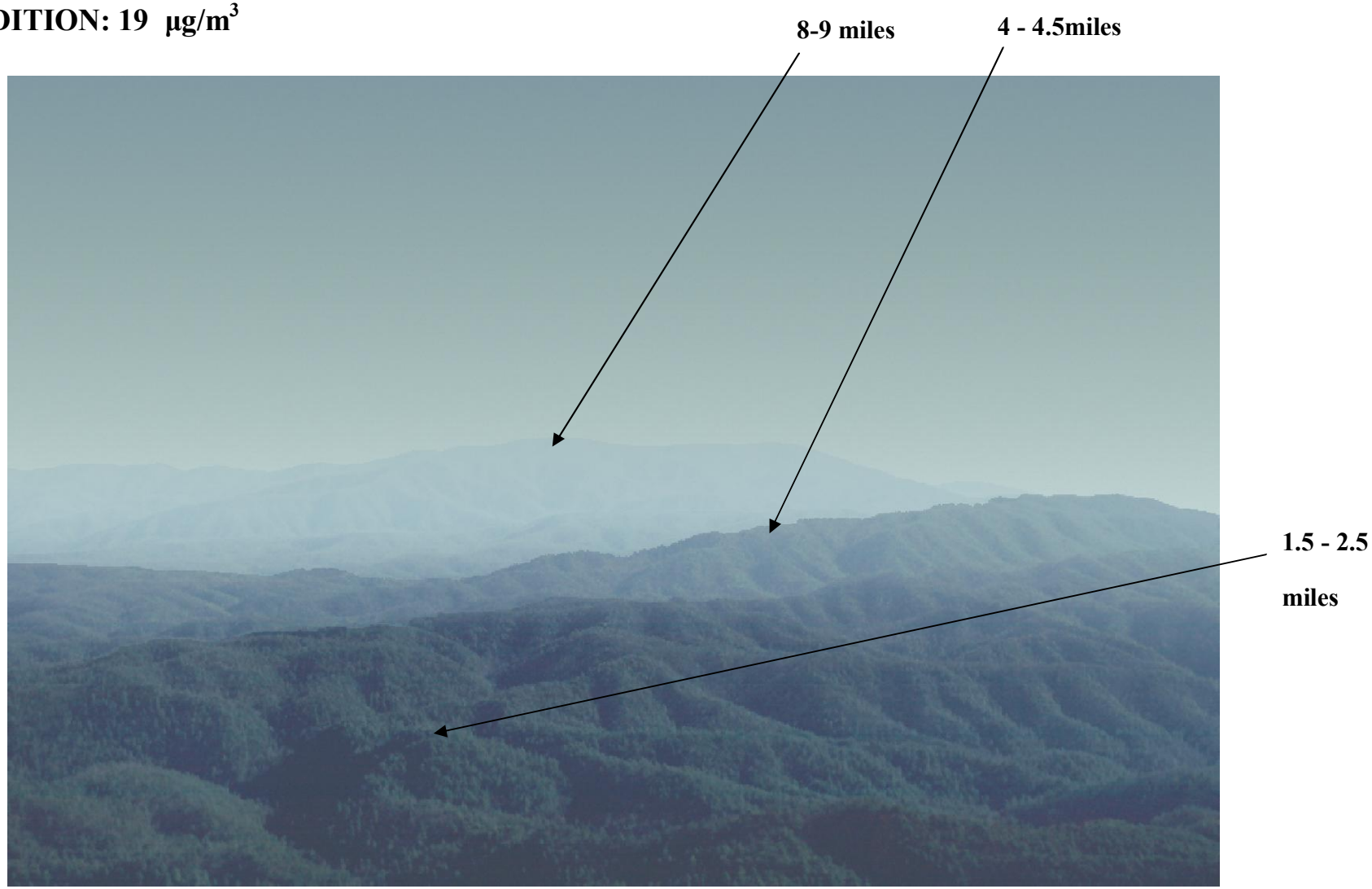
GREAT SMOKY MOUNTAINS N.P., TN

CONDITION: 19 µg/m^3

PM 2.5	**19 µg/m^3**
Relative Humidity	**80%**
Visual Range	**16.5 miles**

GREAT SMOKY MOUNTAINS N.P., TN

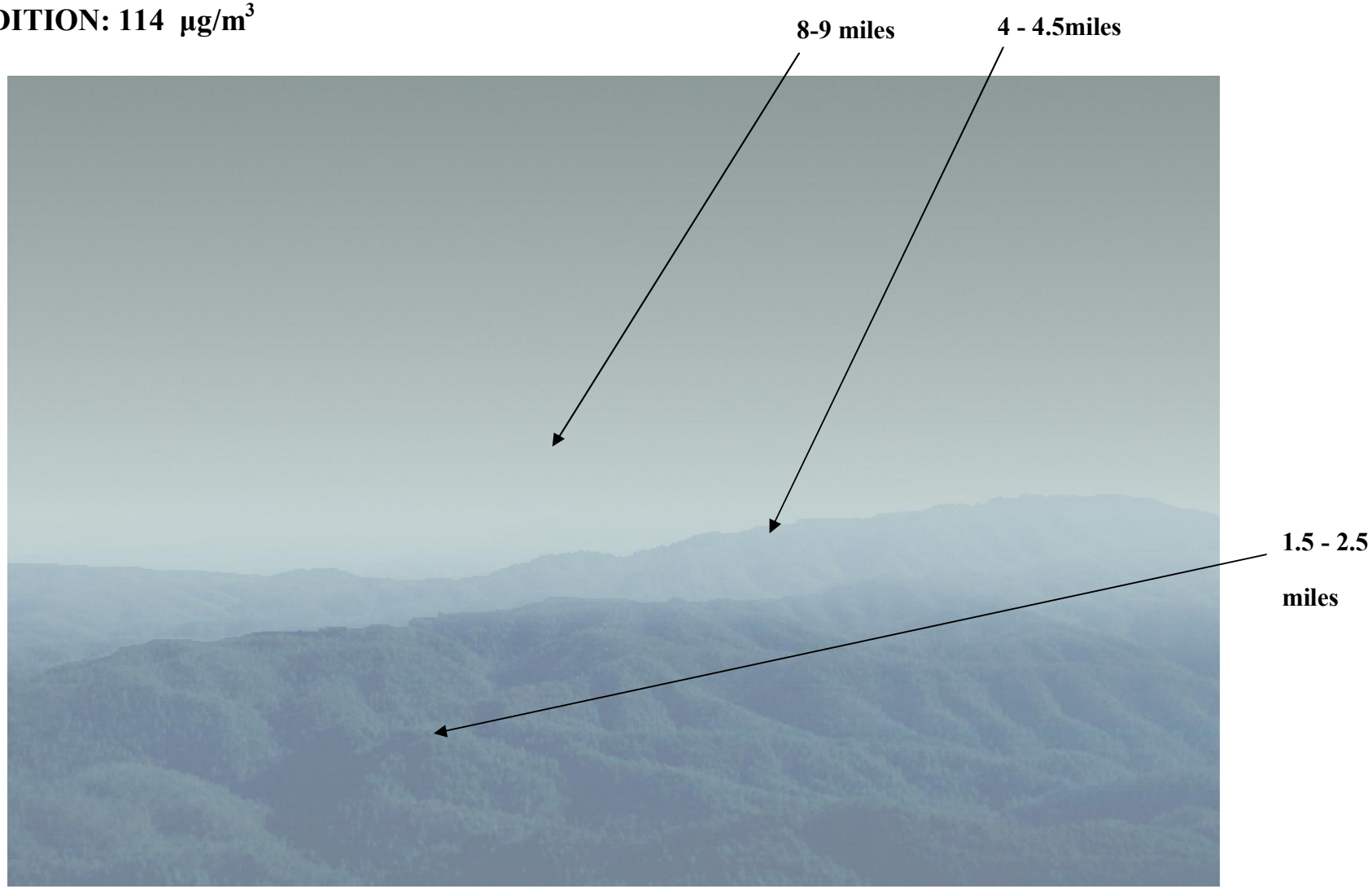
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**90%**
Visual Range	**12.4 miles**

GREAT SMOKY MOUNTAINS N.P., TN

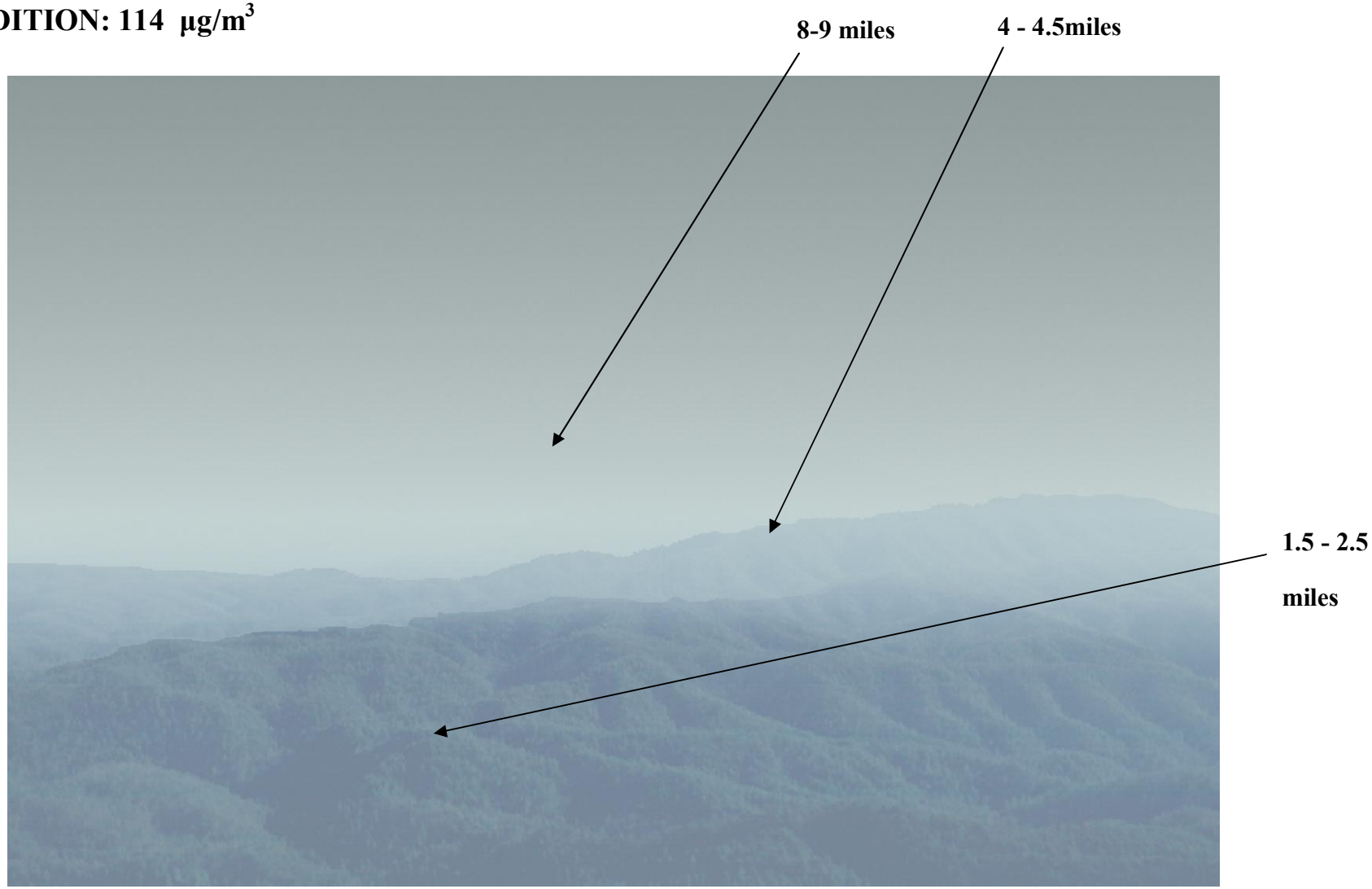
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**40%**
Visual Range	**4.9 miles**

GREAT SMOKY MOUNTAINS N.P., TN

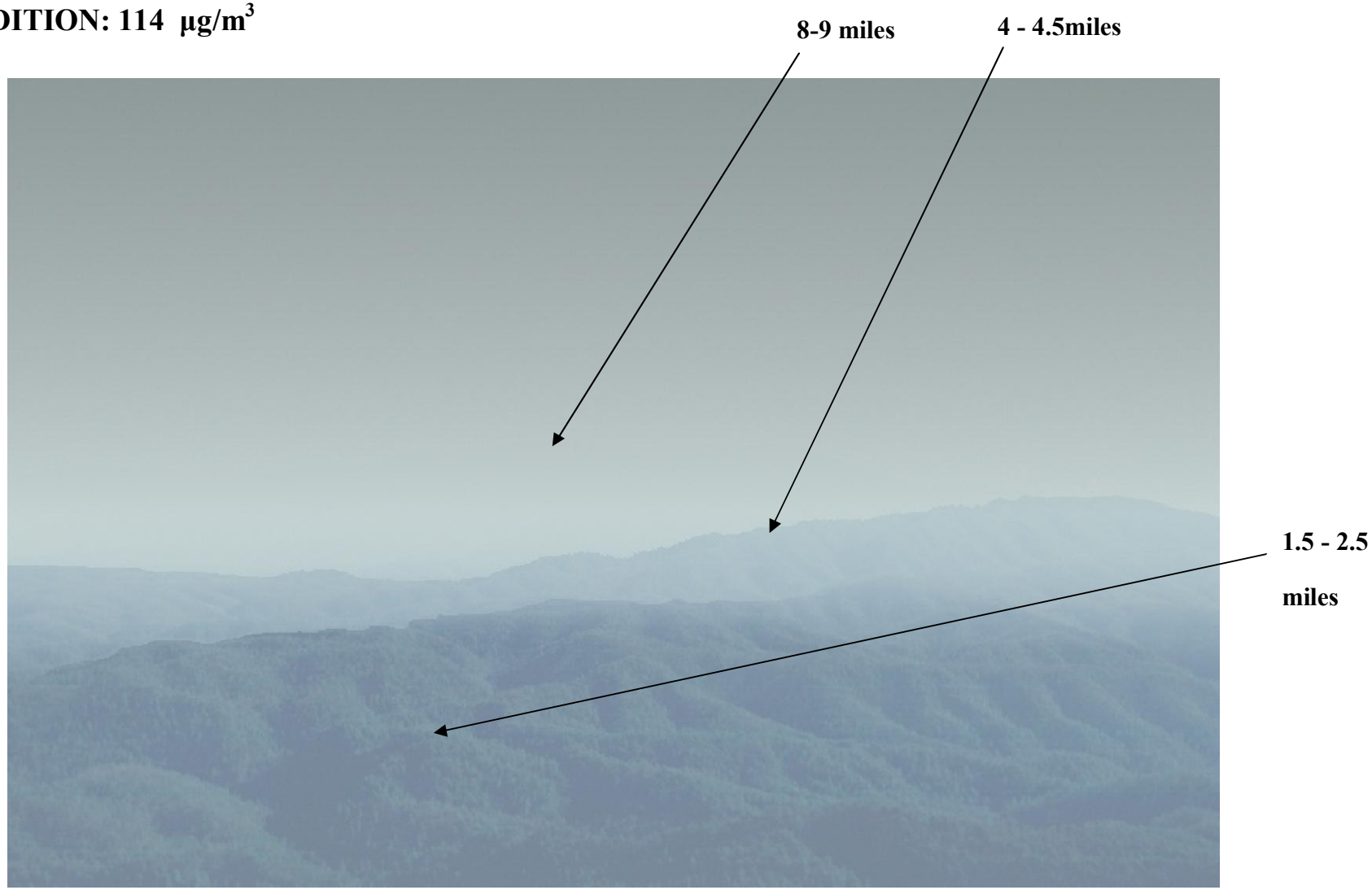
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**50%**
Visual Range	**4.8 miles**

GREAT SMOKY MOUNTAINS N.P., TN

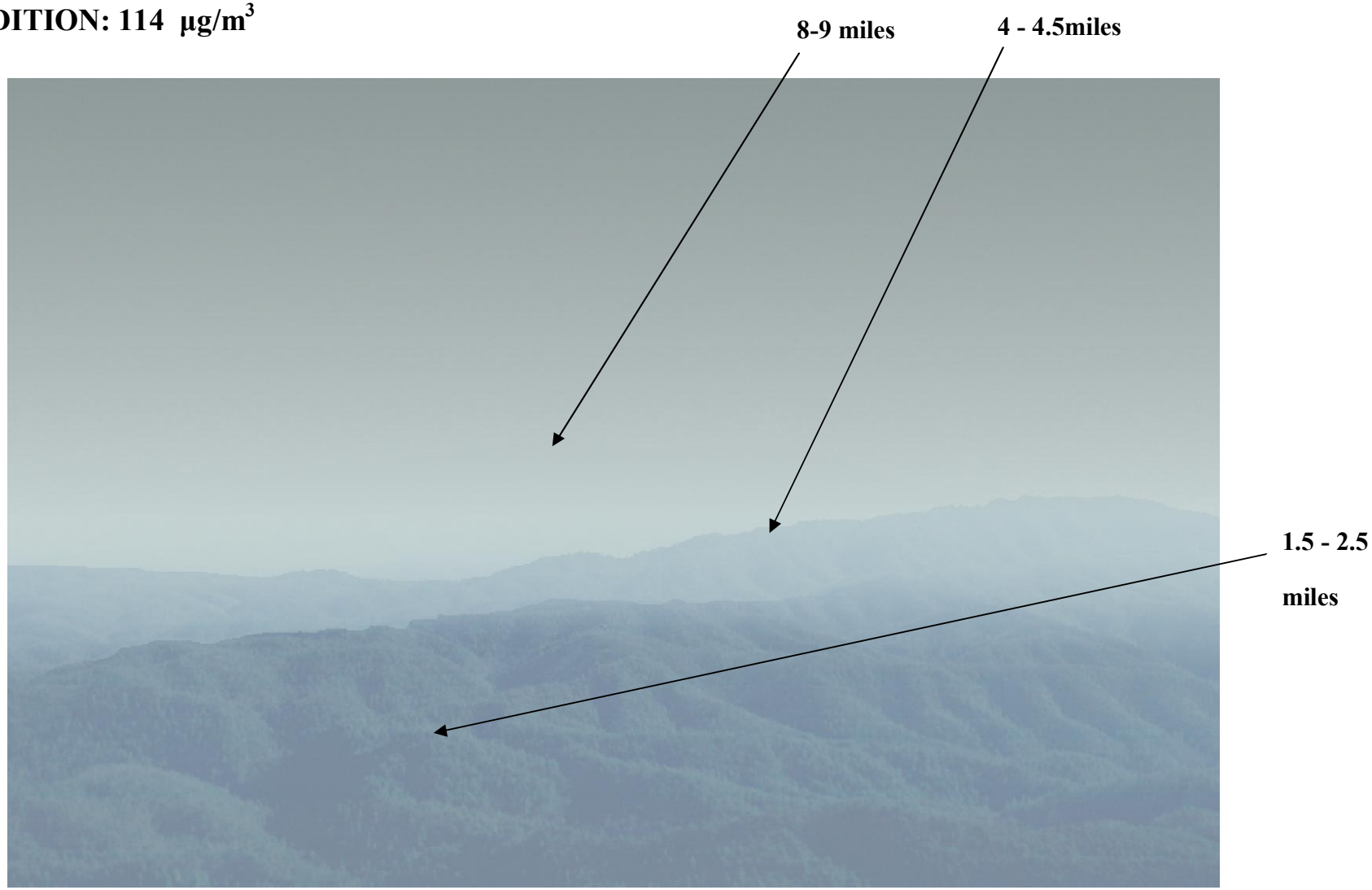
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**60%**
Visual Range	**4.7 miles**

GREAT SMOKY MOUNTAINS N.P., TN

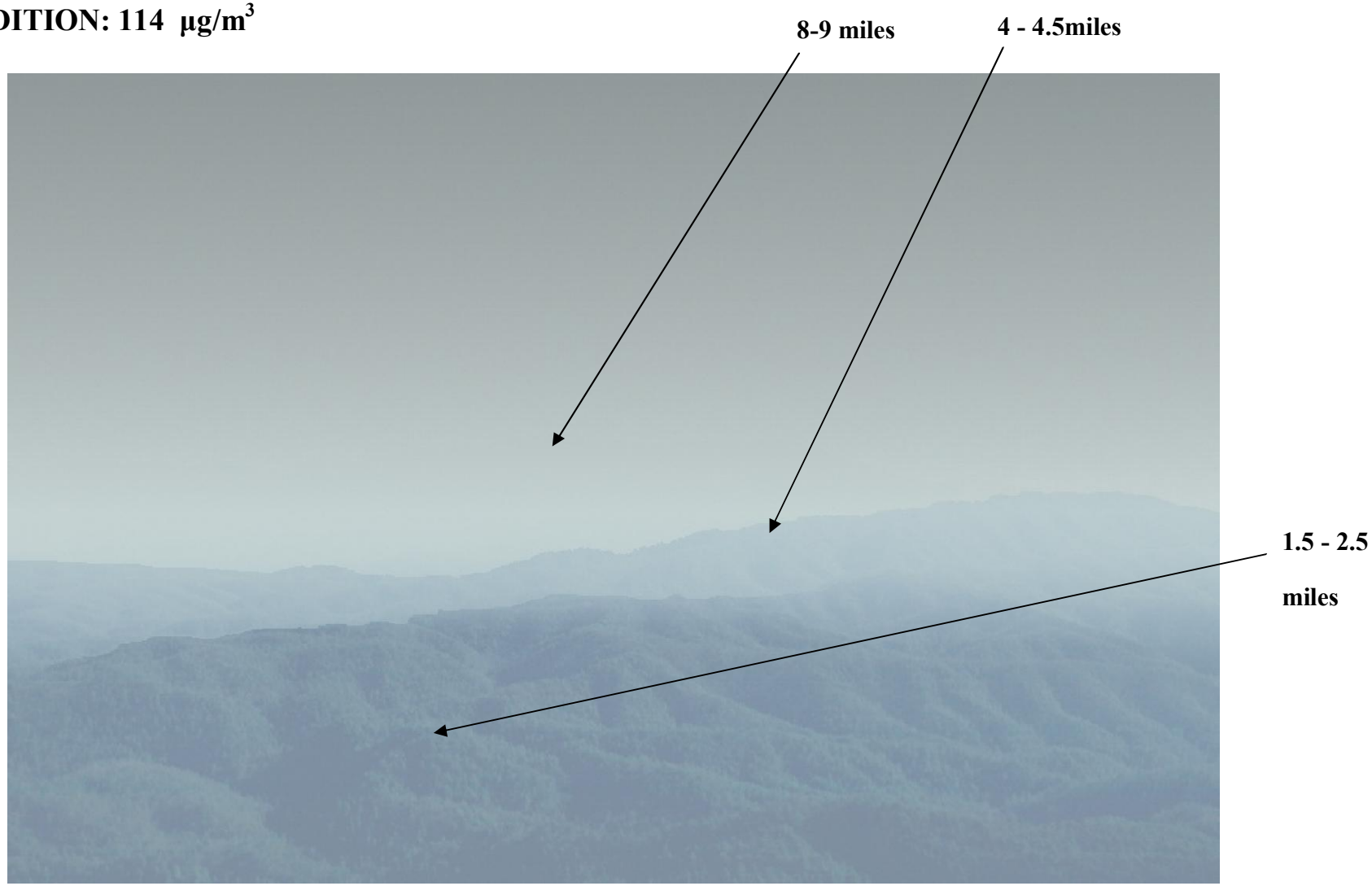
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**70%**
Visual Range	**4.5 miles**

GREAT SMOKY MOUNTAINS N.P., TN

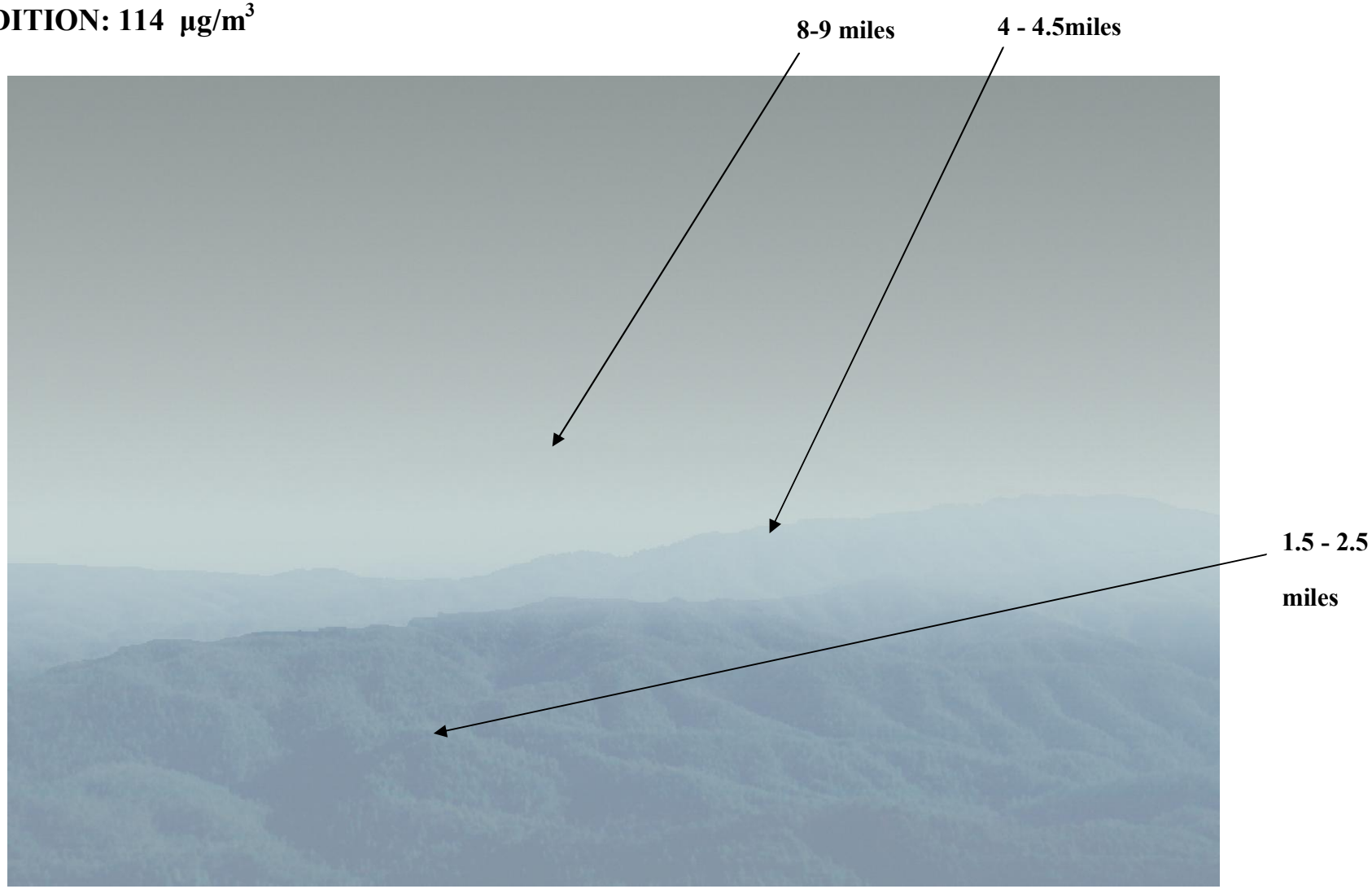
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**80%**
Visual Range	**4.3 miles**

GREAT SMOKY MOUNTAINS N.P., TN

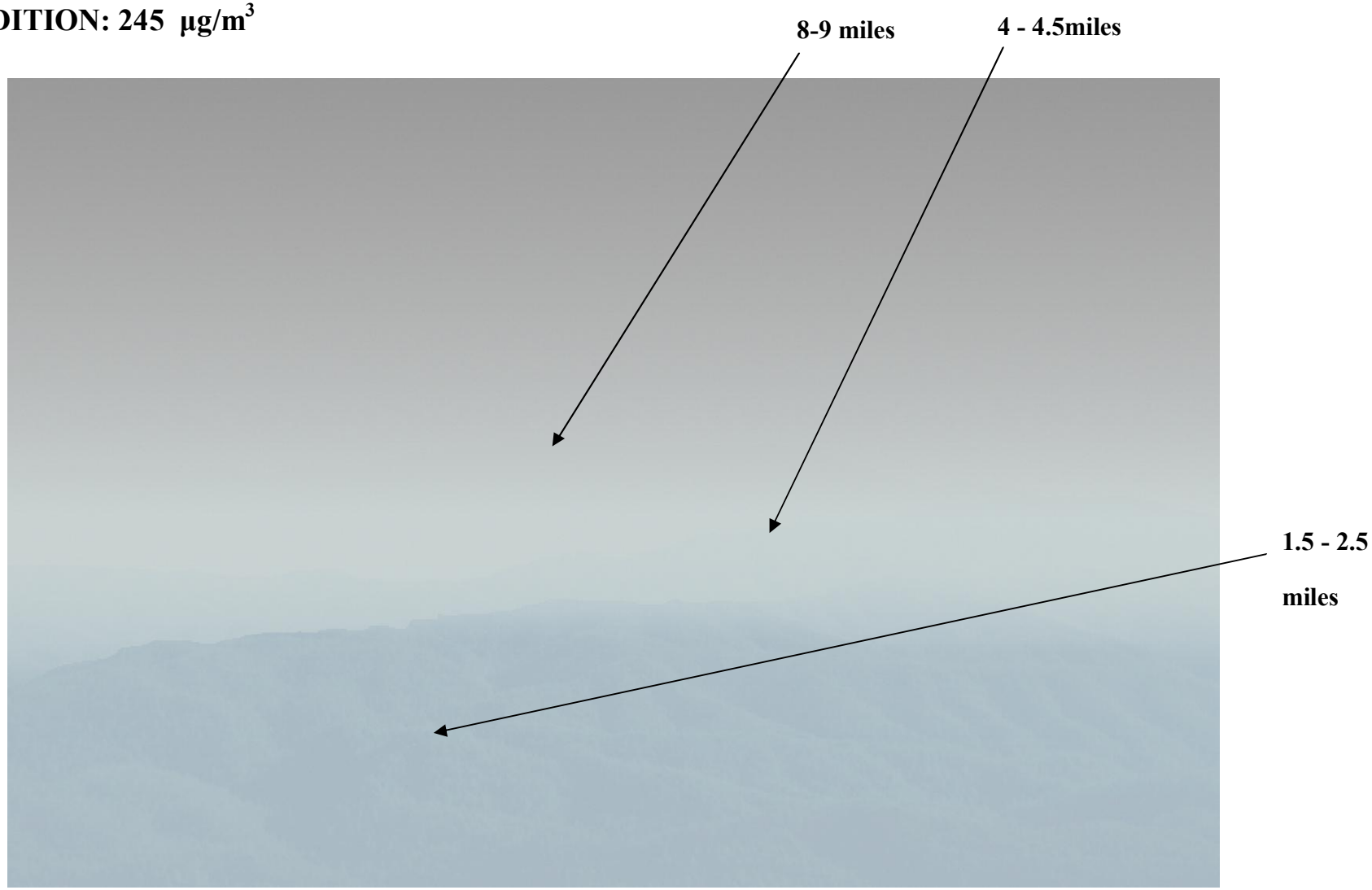
CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**90%**
Visual Range	**4.0 miles**

GREAT SMOKY MOUNTAINS N.P., TN

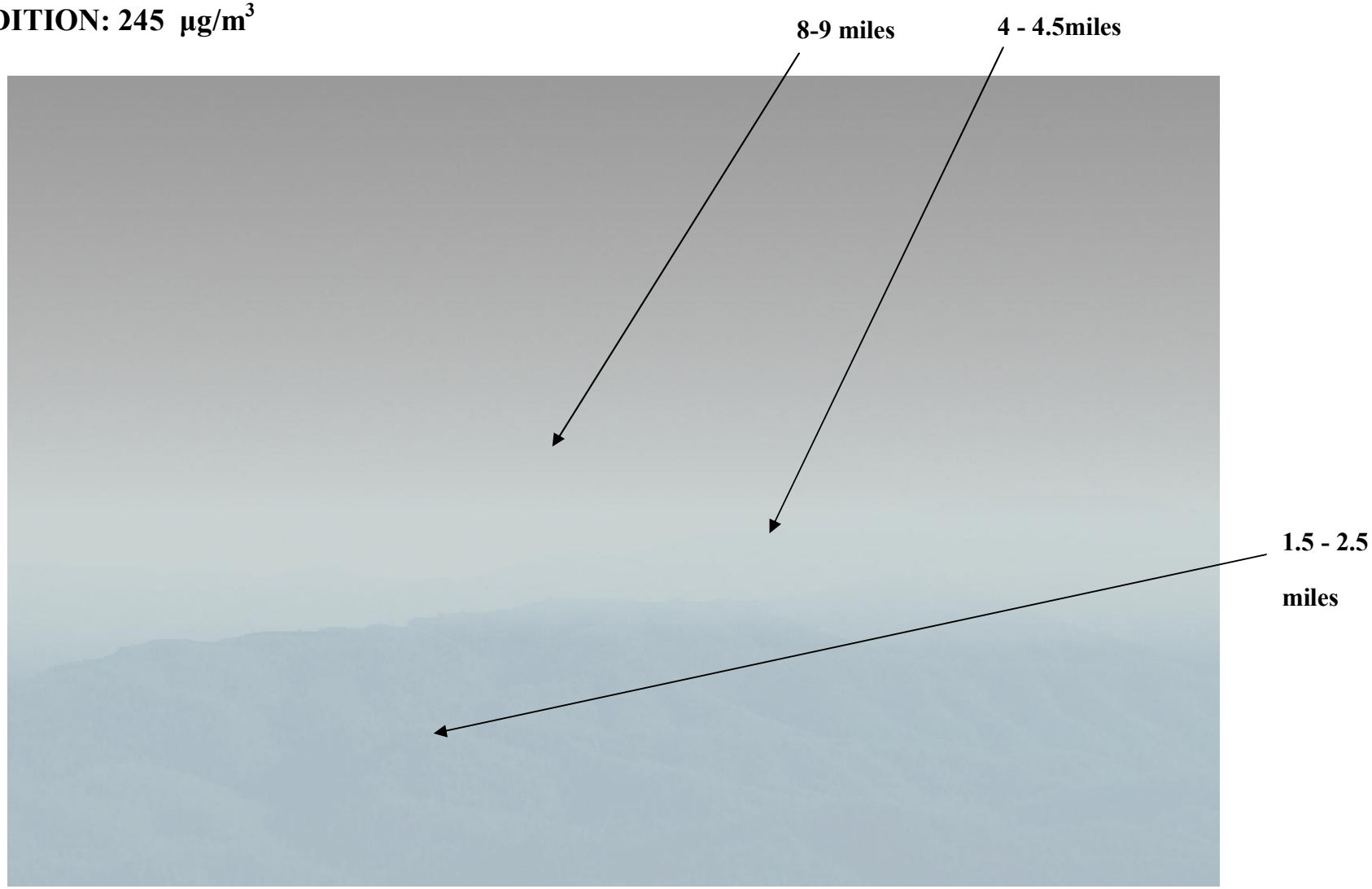
CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**40% - 50%**
Visual Range	**2.3 miles**

GREAT SMOKY MOUNTAINS N.P., TN

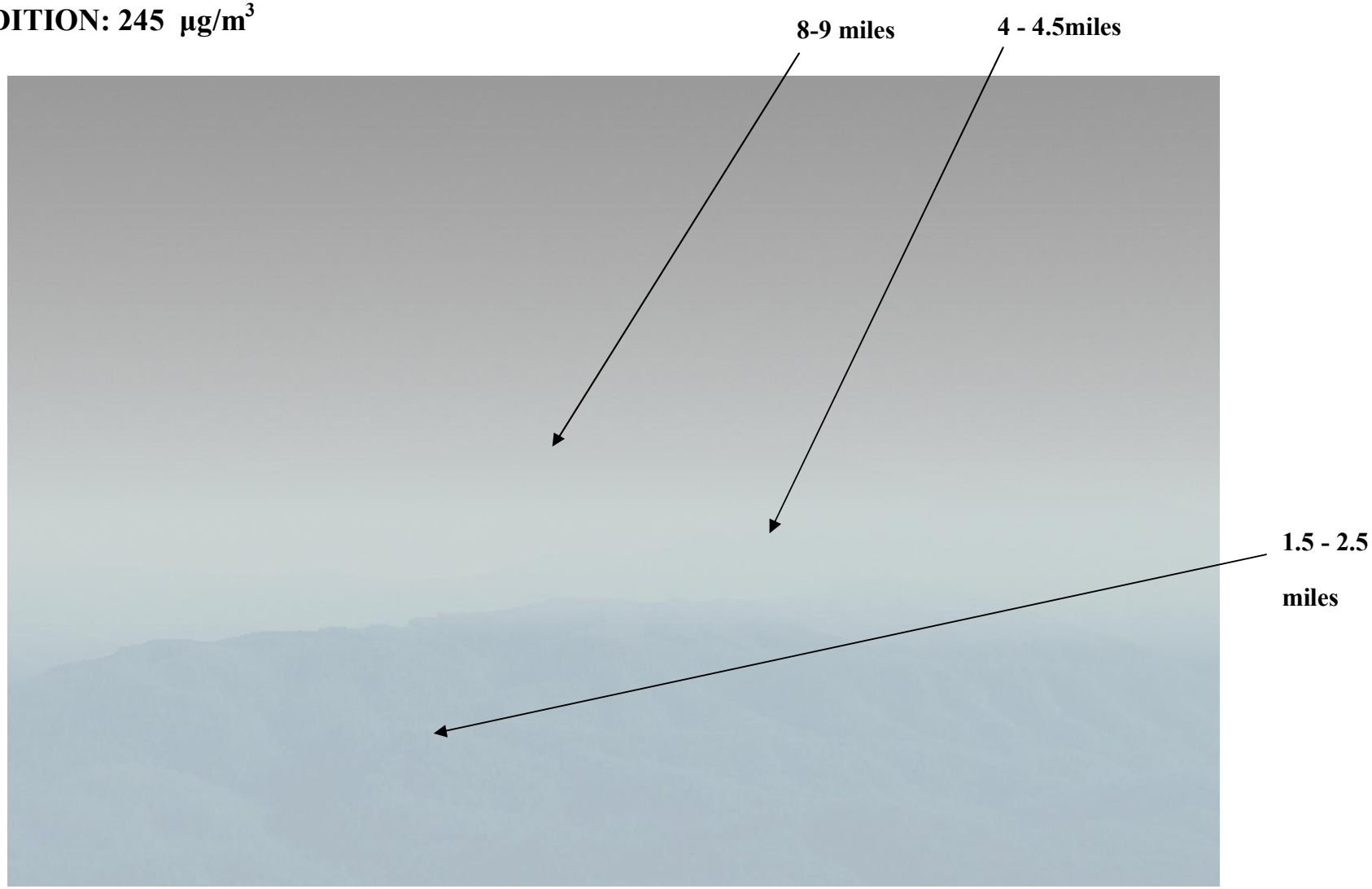
CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**60% - 70%**
Visual Range	**2.2 miles**

GREAT SMOKY MOUNTAINS N.P., TN

CONDITION: 245 µg/m^3



PM 2.5	**245 µg/m^3**
Relative Humidity	**80% - 90%**
Visual Range	**2.1 miles**

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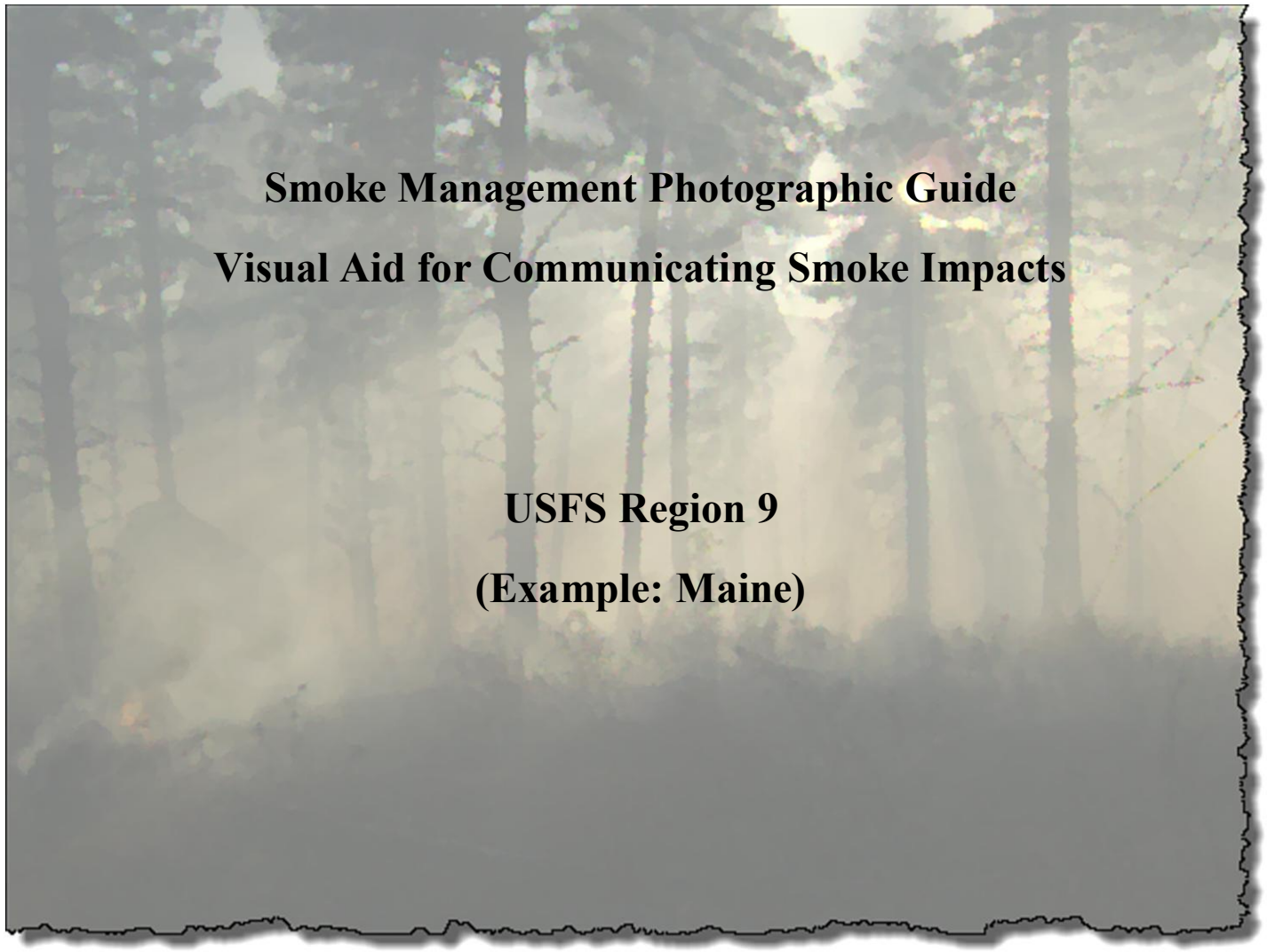


Smoke Management Photographic Guide

Visual Aid for Communicating Smoke Impacts

USFS Region 9

(Example: Maine)

University of Idaho
College of Natural Resources

Development and Scope:
This guide is developed by the University of Idaho College of Natural Resources with images from US National Park and USDA Forest Service locations.

The primary purpose of this guide is to serve as a tool for communicating potential particulate matter (PM 2.5) levels using visual representation. Numerous factors impact visibility; in addition to particulate matter and the presence of ozone (Aherns 2003), visibility is also affected by compounds including ammonium nitrate, ammonium sulfate, and light absorbing carbon (Malm *et al.* 1994), as well as relative humidity (Achtemeier et al. 2001). Existing background levels of visibility also vary across the country (Core 2001). This guide is intended to indicate smoky conditions in USFS Region 9. Due to the complexity of variables, and limitations in the distances perceived by the human eye, visual approximations should be used as indicators, not precise measurement.

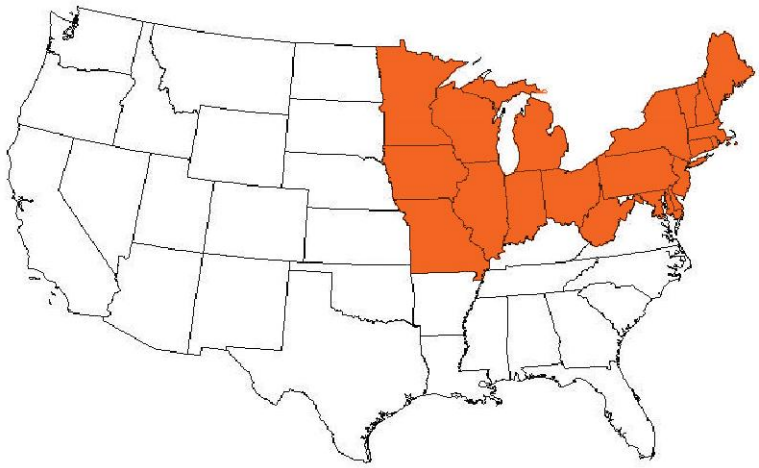


Figure 1 The materials in this guide are for estimation purposes only and indented to represent the overall conditions in the highlighted regions.

Methods
To represent visual impacts from smoke in numerous locations across the Unites States this reference guide has been generated using WinHaze imaging software (Air Resource Specialists Inc. 2013). This software package incorporates several years of particulate data from Class I airsheds throughout the continental United States. The program allows for consistent visual representation of airsheds under varying humidity, background pollutant levels and particulate matter (PM) concentrations based on the IMPROVE equation for estimating ambient light extinction coefficients (Hand and Malm 2006). This methodology facilitates consistent representation of smoky conditions while avoiding variations in sun angle and camera placement that can occur using a more traditional method of matching photographs with monitoring data. Acadia National Park was chosen for this guide based on 986 days of particulate data incorporated into the visual estimates. To establish an image representing the area free of any smoke-impaired visibility a 'baseline' image was generated in WinHaze using the mean values indicated in the table on the left which total less than 5 $\mu g/m^3$ fine particulate matter and less than 5 $\mu g/m^3$ of coarse particulates.

Constituents of PM represented herein ($\mu g/m^3$)		
	Baseline	Elevated
Ammonium Sulfate	1.04	6.83
Ammonium Nitrate	0.13	0.71
Organic Carbon	0.73	-
LAC/Black Carbon	0.18	-
Fine Soil	0.13	0.36
Coarse mass	3.89	5.78

Visual impairment from smoke is simulated first by establishing constant values for the constituent of PM unlikely to change as the result of smoke from fires. 'Elevated' values for ammonium sulfate, ammonium nitrate, fine soil, and coarse mass were determined by using values recorded for the 20% worst visibility days. Organic carbon and Black carbon are then increased to reflect increasing concentrations of smoke, as this carbon

composes nearly 75% of the emissions from forest fires (Andreae & Merlet 2001). The ratio of organic carbon to black carbon will be represented by a 15.4/1 ratio based on estimates for wildland fire in non-tropical forests in a comprehensive review by Andreae & Merlet (2001).

Because relative humidity (RH) impacts visibility and changes throughout the fire season, a range of different RH levels is represented based on morning and afternoon averages. Data for these averages is taken from Portland, ME (NOAA 2013). Values between the months of May and September were chosen to represent the relative humidity levels most likely to be present during the wildland fire season.

This guide represents short-term (1-3 hour) exposure pollutant levels as presented the Wildfire Smoke, A Guide for Public Health Officials (Lipset *et al.* 2008). The categories ('Good', 'Moderate', etc.) use terminology based on the EPA's Air Quality Index (US EPA, 2009). Due to the difficulty of distinguishing a fine scale measurement such as particulate concentration by using eyesight alone, three values were chosen, each in the mid-range of a health effect index category (*below*).

EPA Values for PM		Concentrations
AQI Value	Actions to protect your health from particle pollution	PM2.5 or PM10 Levels ($\mu g/m^3$) 1 to 3 hour average
Good (0-50)	None	0-38
Moderate (51-100)	Unusually sensitive people should consider reducing prolonged or heavy exertion.	39-88
Unhealthy for Sensitive Groups 101-150	The following groups should reduce prolonged or heavy outdoor exertion: -People with heart or lung disease -Children and older adults Everyone else should limit prolonged or heavy exertion	89-138
Unhealthy (151-200)	The following groups should avoid all physical outdoors: -People with heart or lung disease -Children and older adults Everyone else should avoid prolonged or heavy exertion	139-351
Very Unhealthy (201-300)	The following groups should remain indoors and keep activity levels low: -People with heart or lung disease -Children and older adults Everyone else should avoid all physical activity outdoors	352-526+

19 $\mu g/m^3$

114 $\mu g/m^3$

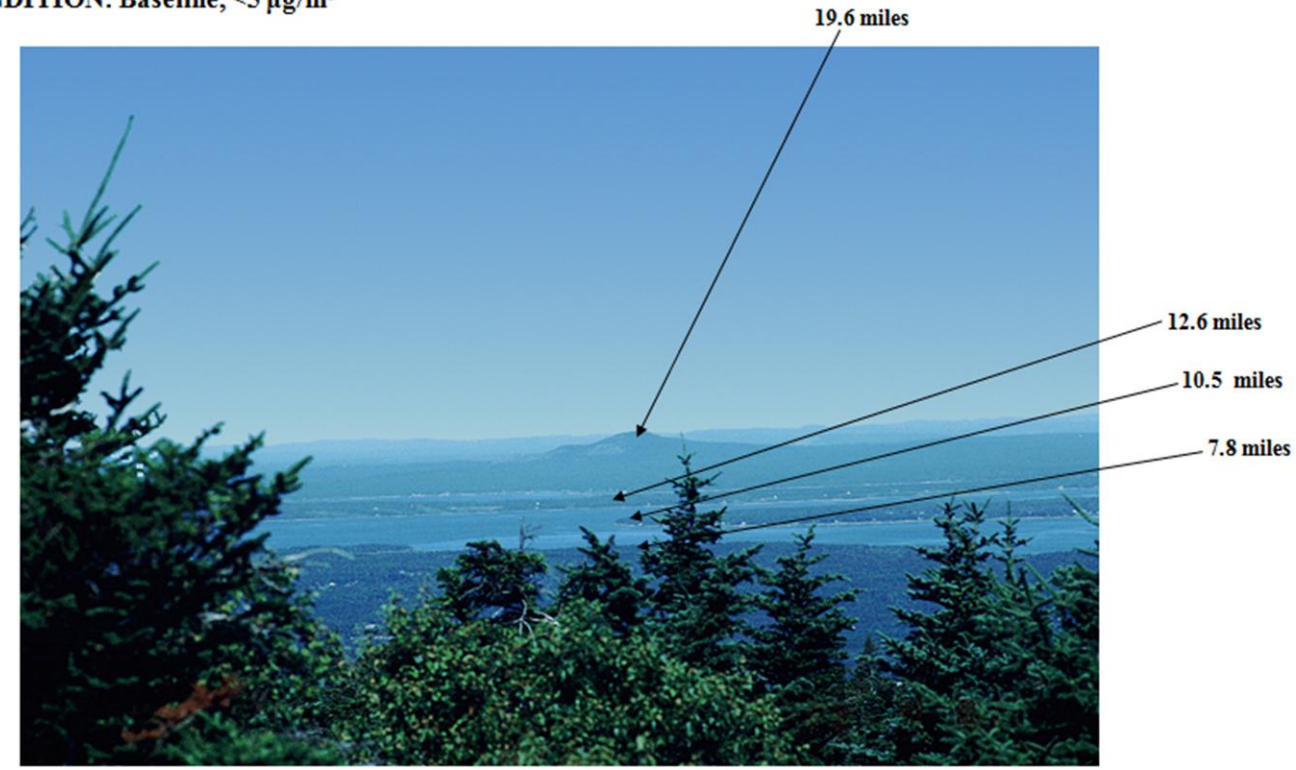
245 $\mu g/m^3$

Using this guide:

To use this guide to represent particulate matter, compare your line of site with landmarks similar distances as those depicted here-in. When making this comparison, face away from the sun. Use points on the landscape of known distances that you are familiar with. Several examples of the same concentration are represented with varying relative humilities based on what is likely to be encountered during the fire season.

ACADIA NATIONAL PARK, ME

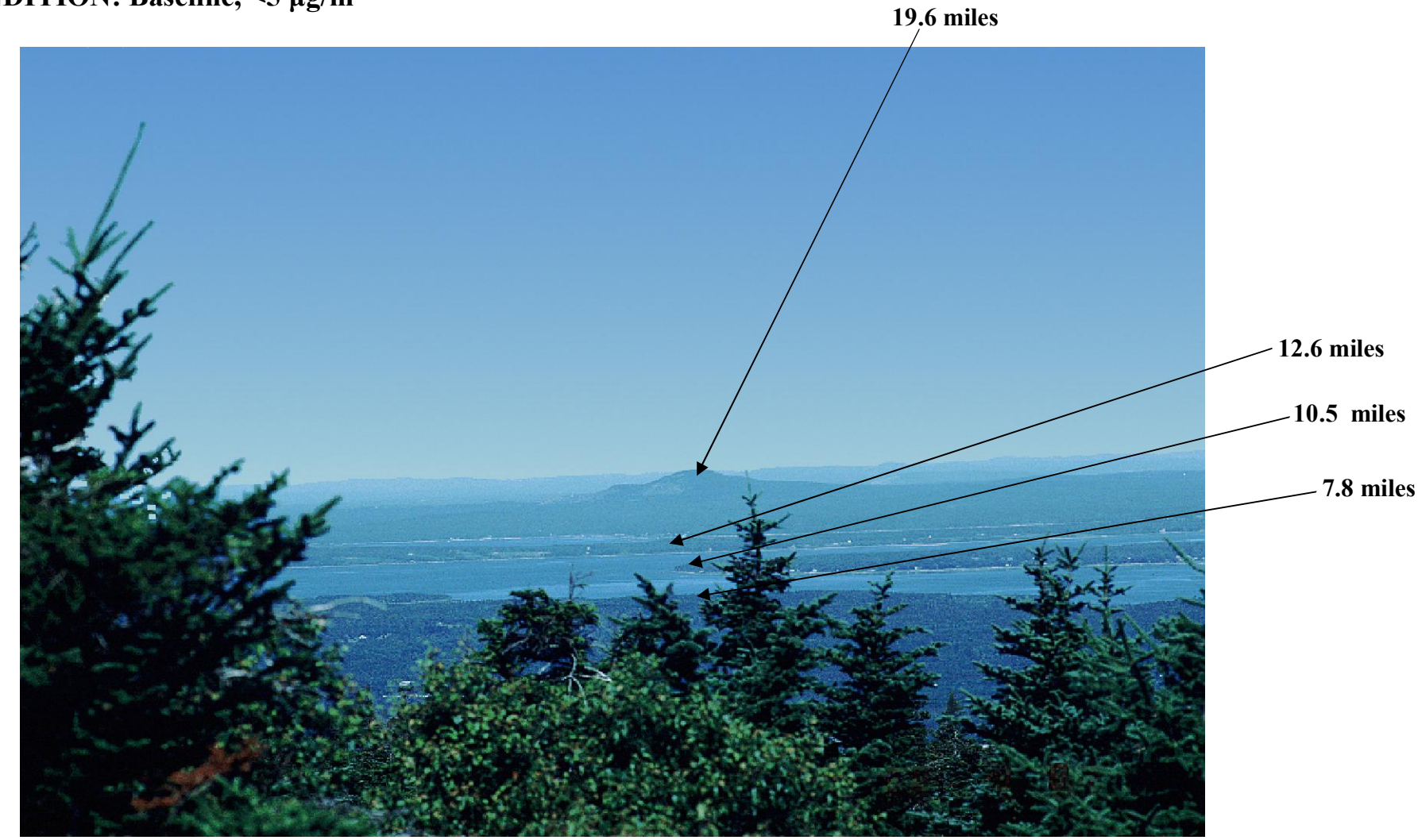
CONDITION: Baseline, <5 µg/m³



PM 2.5	<5.0 µg/m³
Relative Humidity	50 %
Visual Range	111.2 miles

ACADIA NATIONAL PARK, ME

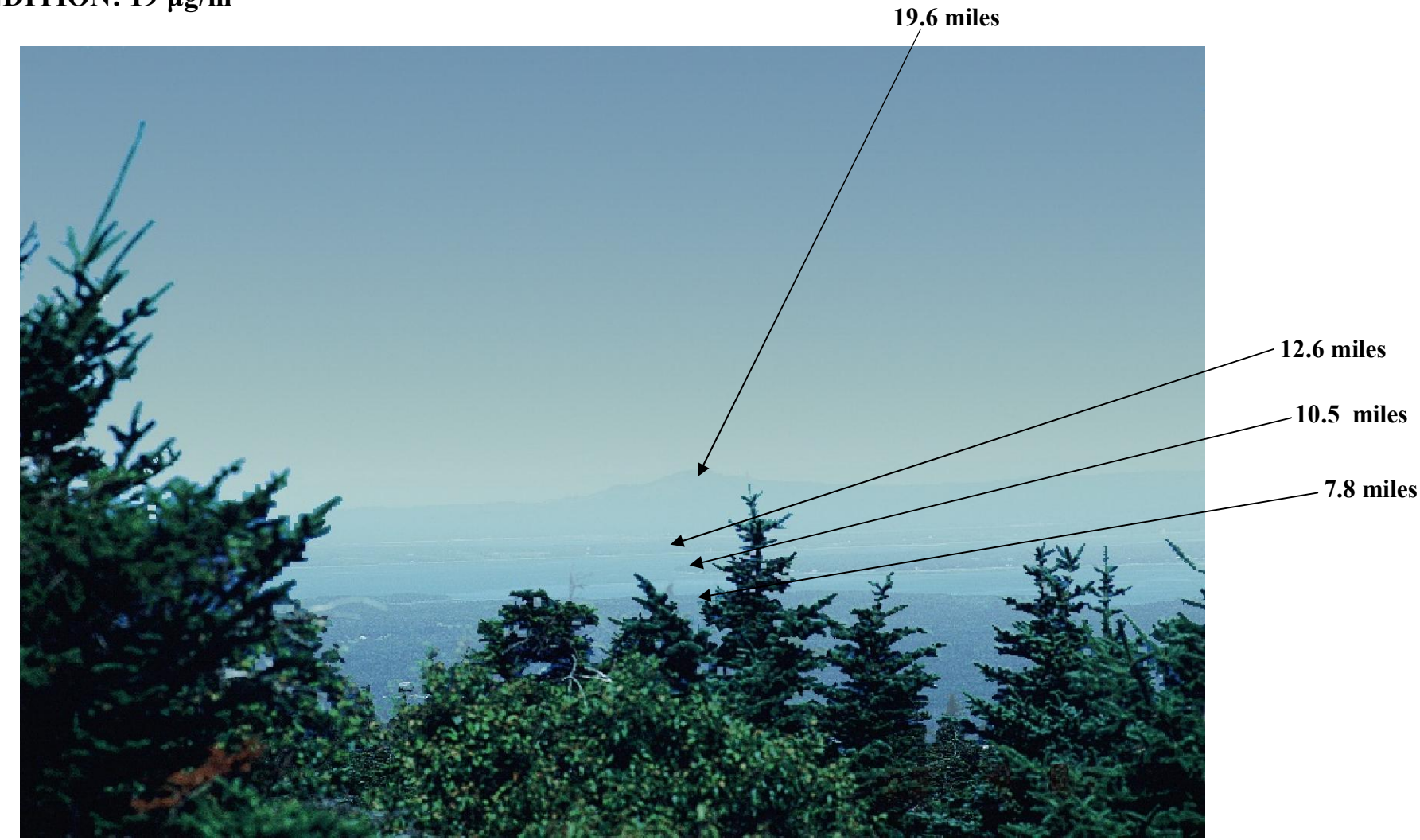
CONDITION: Baseline, <5 µg/m^3



PM 2.5	**<5.0 µg/m^3**
Relative Humidity	**50 %**
Visual Range	**111.2 miles**

ACADIA NATIONAL PARK, ME

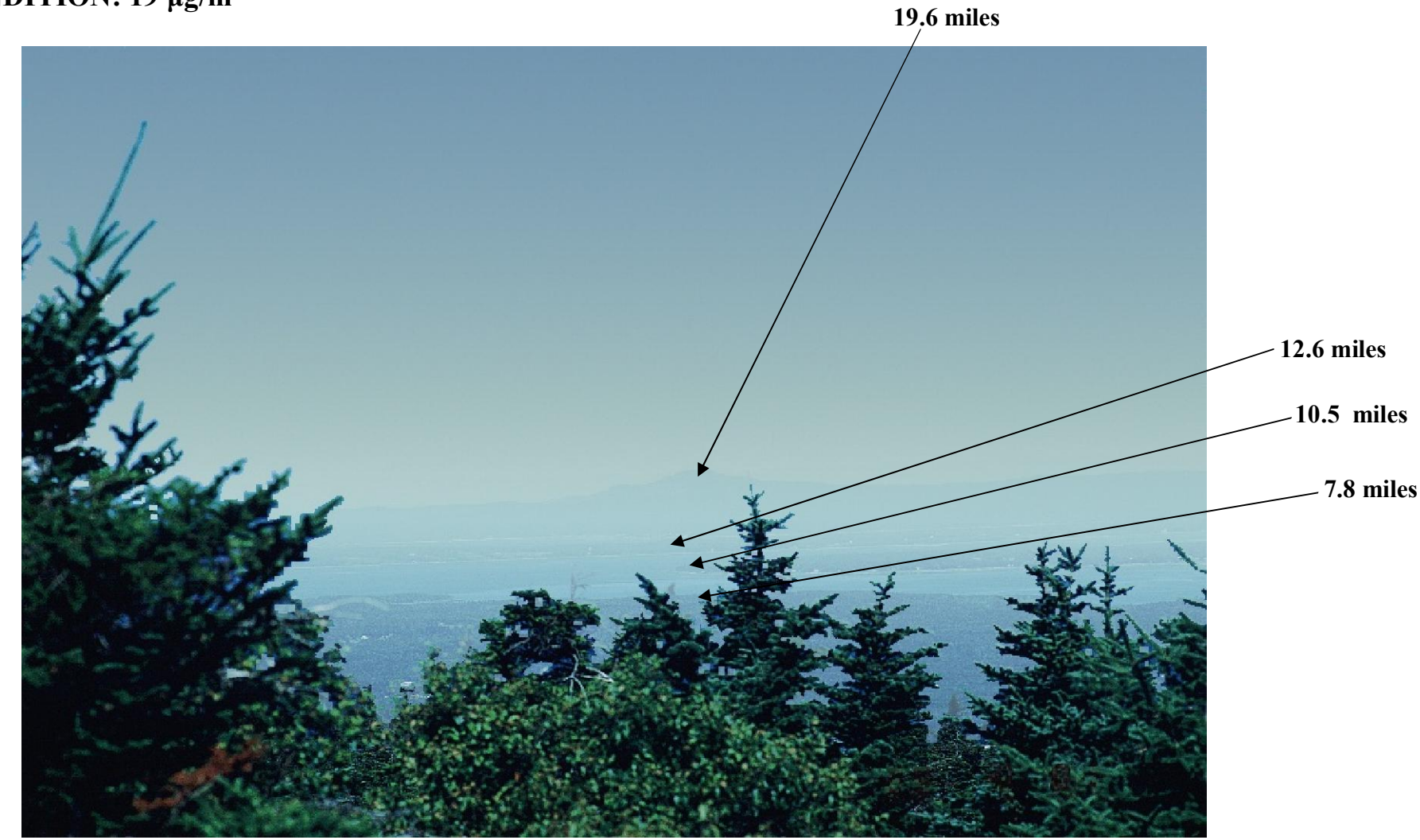
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**50 %**
Visual Range	**26.3 miles**

ACADIA NATIONAL PARK, ME

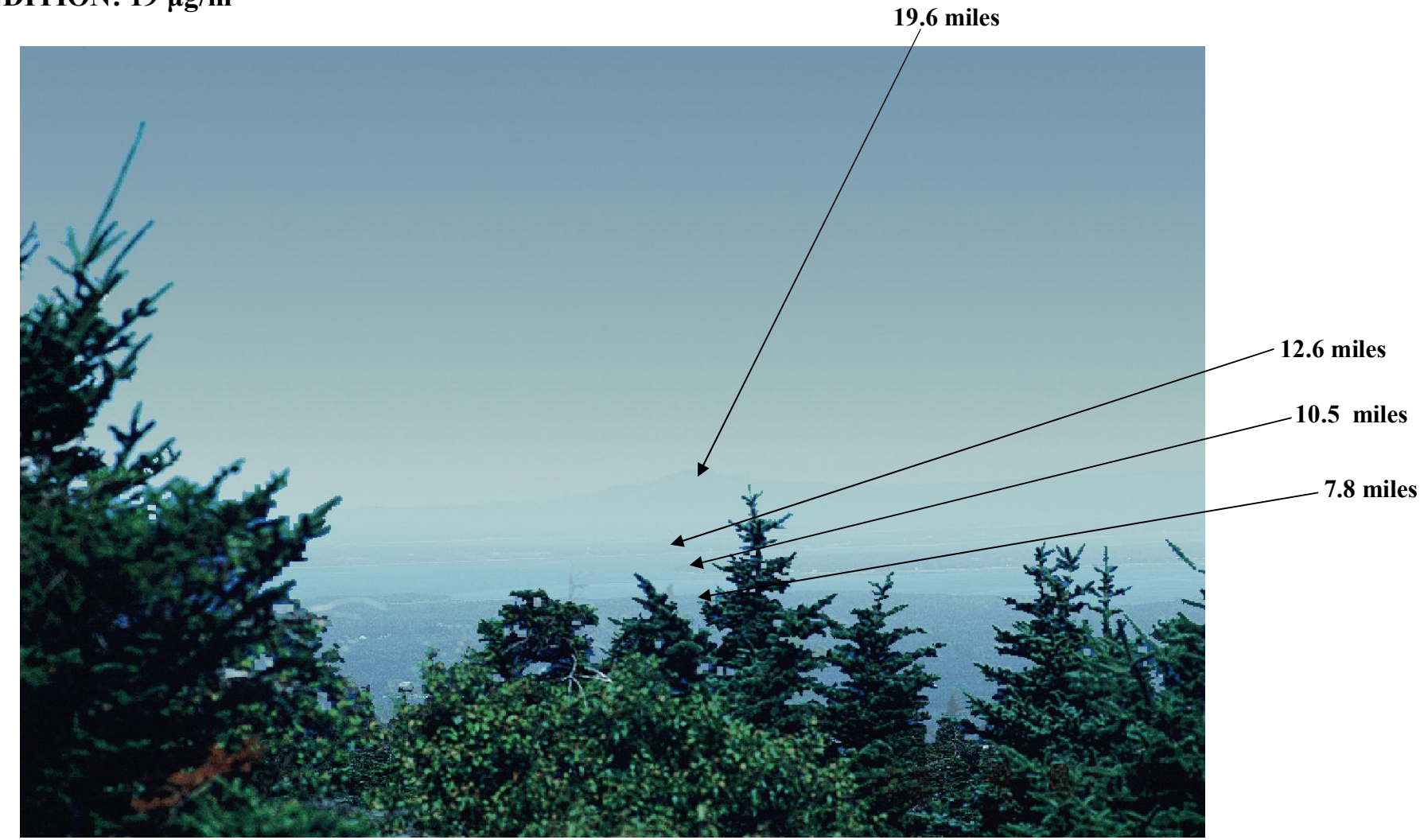
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**60 %**
Visual Range	**24.4 miles**

ACADIA NATIONAL PARK, ME

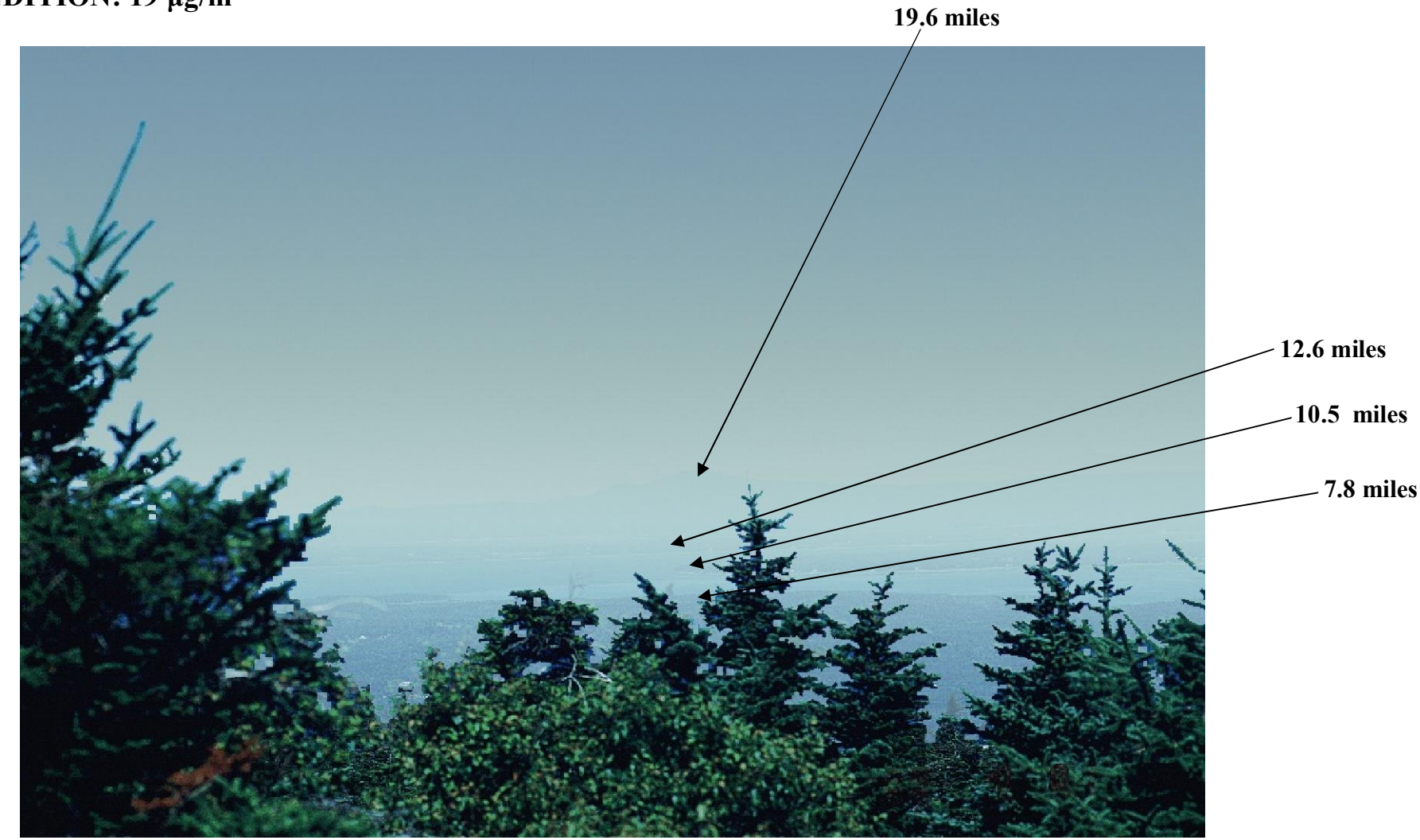
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**70 %**
Visual Range	**22.1 miles**

ACADIA NATIONAL PARK, ME

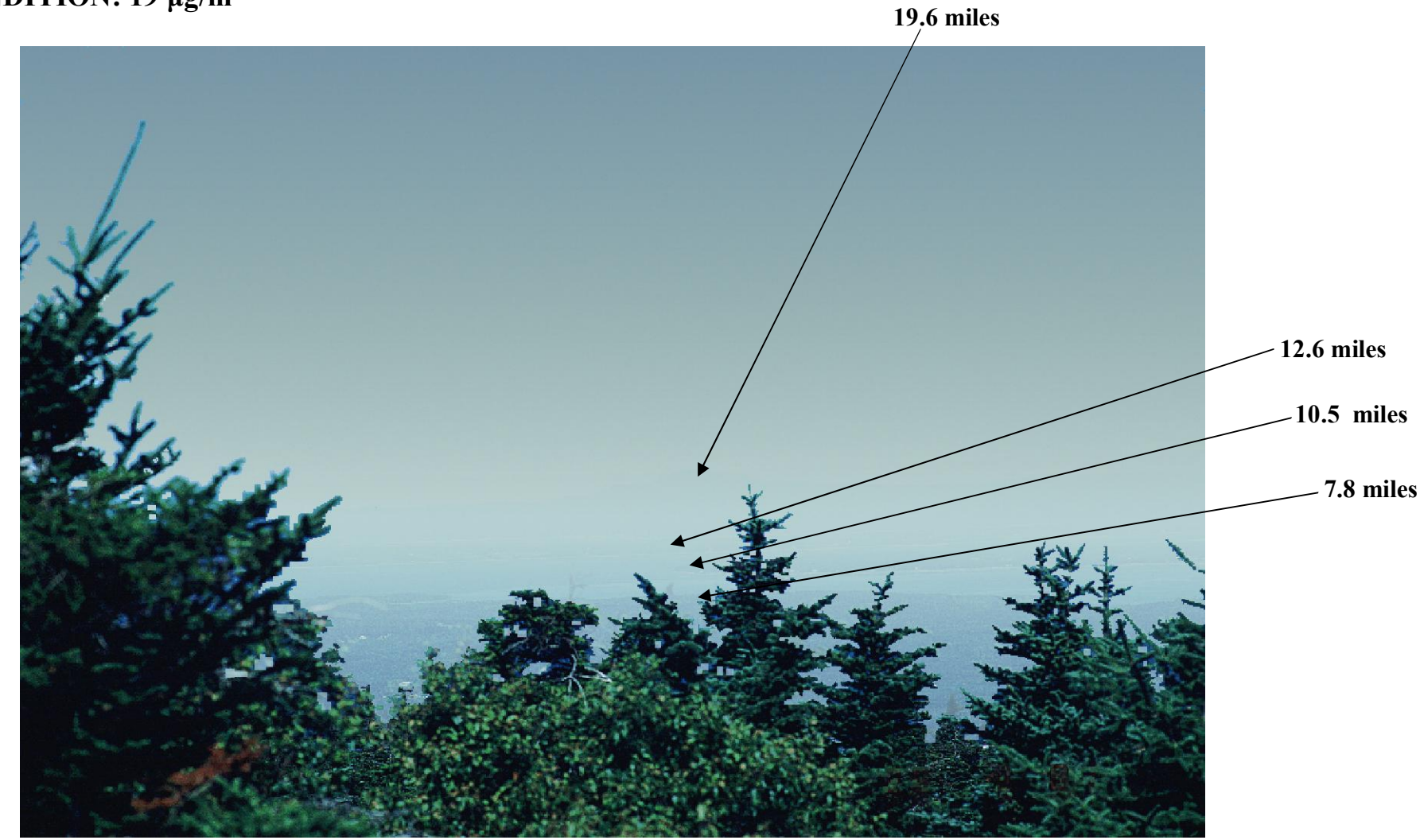
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**80 %**
Visual Range	**19.6 miles**

ACADIA NATIONAL PARK, ME

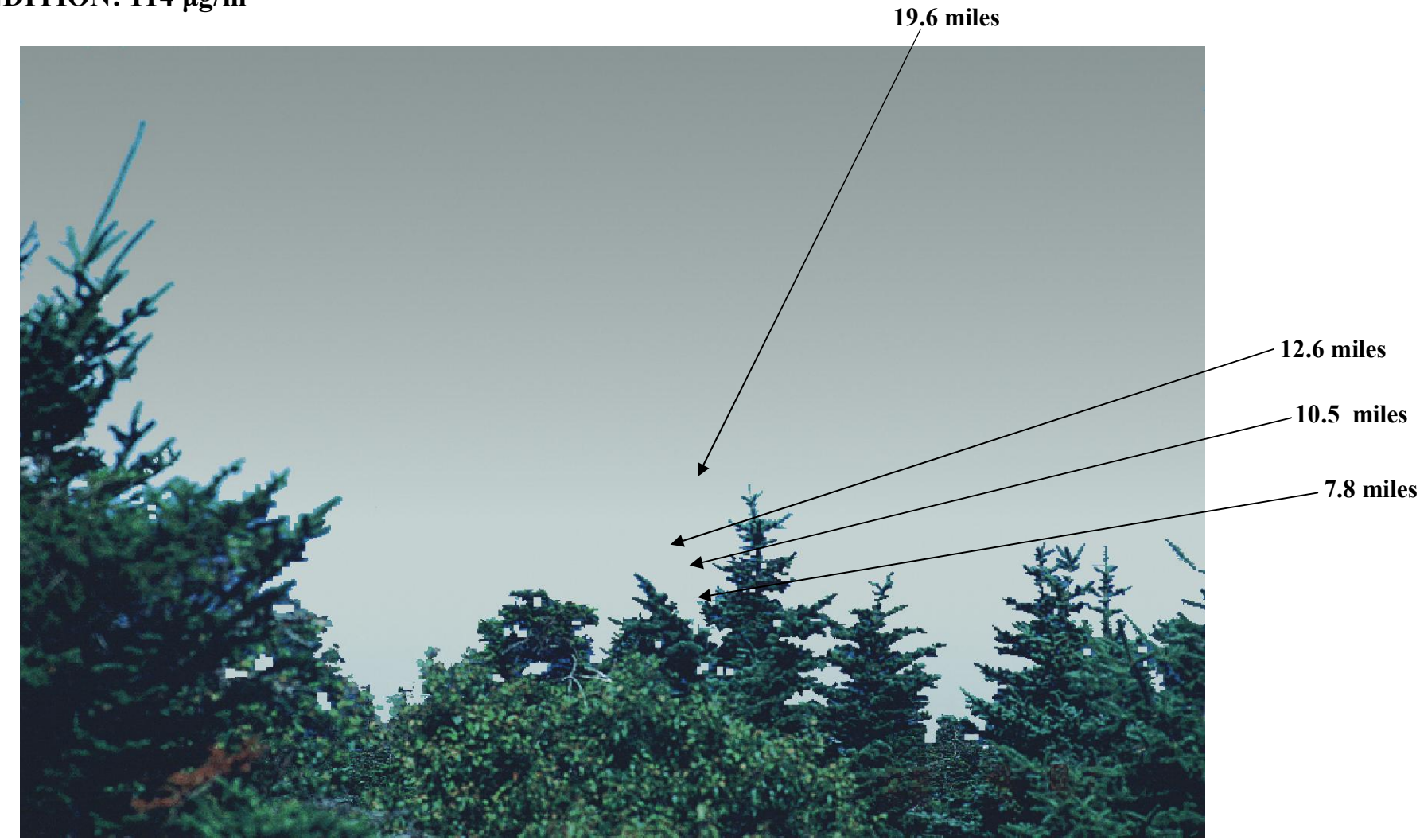
CONDITION: 19 µg/m^3



PM 2.5	**19 µg/m^3**
Relative Humidity	**90 %**
Visual Range	**16.3 miles**

ACADIA NATIONAL PARK, ME

CONDITION: 114 µg/m^3



PM 2.5	**114 µg/m^3**
Relative Humidity	**50 %**
Visual Range	**4.8 miles**

References

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