3.0 FREQUENCY, CHARACTER, AND INTENSITY OF HAZE

This section documents the frequency with which different levels of light scattering occur, and how these relate to frequencies measured within and near Class I areas. Visual observations of uniform and layered hazes are summarized. Hourly measurements of light scattering at each of the MZVS measurement sites are compared and examined to identify periods of extreme light scattering that need to be studied in greater detail. For the six- and twelve-hour periods for which particle absorption measurements were available, the relative contributions of the different components of light extinction are summarized and compared for each sampling site during Intensive Operating Periods.

Light reflected from an object is transmitted through the atmosphere, where its intensity is attenuated when it is scattered and absorbed by gases and particles. The sum of these scattering and absorption coefficients yields the extinction coefficient (b_{ext}) expressed in units of inverse megameters ($Mm^{-1}=1/10^6$ m). Typical extinction coefficients range from ~10 Mm^{-1} in pollution-free air to ~1,000 Mm^{-1} in extremely polluted air (Trijonis *et al.*, 1990). The inverse of b_{ext} corresponds to the distance (in 10^6 m) at which the original intensity of transmitted light is reduced by approximately two-thirds.

Light is scattered when diverted from its original direction by matter (Malm, 1979; Watson and Chow, 1994). The presence of atmospheric gases, such as oxygen and nitrogen, would limit horizontal visual range to ~400 km (if such a sight path were possible); these gases obscure many of the attributes of a target at less than half this distance. This "Rayleigh" or clean air scattering is the major component of light extinction in areas where pollution levels are low, and it can be accurately estimated from temperature and pressure measurements (Edlen, 1953; Penndorf, 1957). Values for clean air scattering at each of the MZVS sites are as follows for the range of wavelengths measured with the OPTEC nephelometer:

Buffalo Pass:	8.4 Mm^{-1}
Gilpin Creek:	8.8 Mm^{-1}
Juniper Mountain:	9.2 Mm^{-1}
Baggs:	9.5 Mm^{-1}
Hayden VOR:	9.4 Mm^{-1}
Hayden Waste Water:	9.6 Mm^{-1}

Light is also scattered by particles suspended in the atmosphere, and the efficiency of this scattering per unit mass concentration is largest for particles with sizes comparable to the wavelength of light (~500 nm). Light is absorbed by nitrogen dioxide (NO_2) gas (Dixon, 1940), black carbonaceous particles (Horvath, 1993), and nontransparent geological material. NO_2 concentrations in excess of 60 $\mu g/m^3$ (30 ppbv) are needed to exceed Rayleigh scattering, and these levels are not found in pristine areas.

Sunlight illuminating the view path is also scattered toward the observer. This air light, also termed the "path radiance," increases with distance from the target while the light reflected from the target decreases due to scattering and absorption (Richards, 1990). For a given composition of the intervening atmosphere, a viewing distance to the target is achieved where the scattered air light overwhelms the transmitted light and the object can no longer be discerned from the horizon sky against which it is viewed. This distance is termed the "visual range" and, under homogeneous illumination and uniform atmospheric composition, is inversely related to the extinction coefficient (visual range = $3.91/b_{ext}$). This "Koschmeider formula" is not perfect because it involves several assumptions that are not always true (Koschmeider, 1924). In particular, the Koschmeider formula assumes that the observer's eye can distinguish contrast differences between the target and horizon sky of 2%, regardless of the nature of the target, the angle of illumination, and the observer's eye.

Light extinction measurements do not fully represent the way people perceive a view. This perception depends on complex interactions among physiological, psychological, and cultural variables that are not completely defined, let alone measurable (Henry *et al.*, 1987; Malm *et al.*, 1981). Pleasing vistas often contain details such as color and texture that make them interesting. Sharp delineations, specifically different colored strata or jagged edges in rock outcroppings, are often considered to provide a pleasing view, as they do in and around the Mt. Zirkel Wilderness. Daytime classifications of scenes recorded by video and color slide, though less quantitative than light scattering and absorption measurements, are important complements to the objective measures. Since visibility is appreciated as an event, rather than an average, frequencies and durations of different extinction levels are more meaningful quantifiers than are long-term averages.

3.1 Light Scattering and Extinction in the Mt. Zirkel Wilderness and Other Class I Areas

The **I**nteragency **M**onitoring of **Pro**tected **V**isual **E**nvironments (IMPROVE) network and IMPROVE protocol monitoring sites have obtained optical, aerosol, and photographic measurements at several Class I wilderness areas and national parks throughout the United States since 1987. Figure 3.1.1 shows IMPROVE sites that acquired light scattering (b_{scat}) measurements with OPTEC nephelometers identical to those used in the MZVS and light extinction (b_{ext}) measurements with sight path transmissometers.

As will be shown in Section 3.5, particle absorption accounts for no more than 20% of b_{ext} in the MZVS study area and is often negligible. Light scattering is, therefore, an adequate surrogate for total light extinction, and at most might be increased by 2 or 3 Mm^{-1} to account for particle absorption. Scattering and extinction values are summarized in Table 3.1.1 for the MZVS study period as 10th, 50th, and 90th percentile values for b_{scat}. Following IMPROVE reporting conventions, data are filtered for weather events by eliminating values corresponding to relative humidity exceeding 90%. The percentiles reported in Table 3.1.1 represent hours when visibility is not directly influenced by rain, snow, or fog at the monitoring site or along a sight path. At high elevation mountain sites, such as Buffalo Pass, as much as 60% of hourly values collected during the winter are weather affected.

Table 3.1.1 shows that the Buffalo Pass, Gilpin Creek, and Juniper Mountain sites experience among the lowest light scattering and extinction of all IMPROVE and IMPROVE

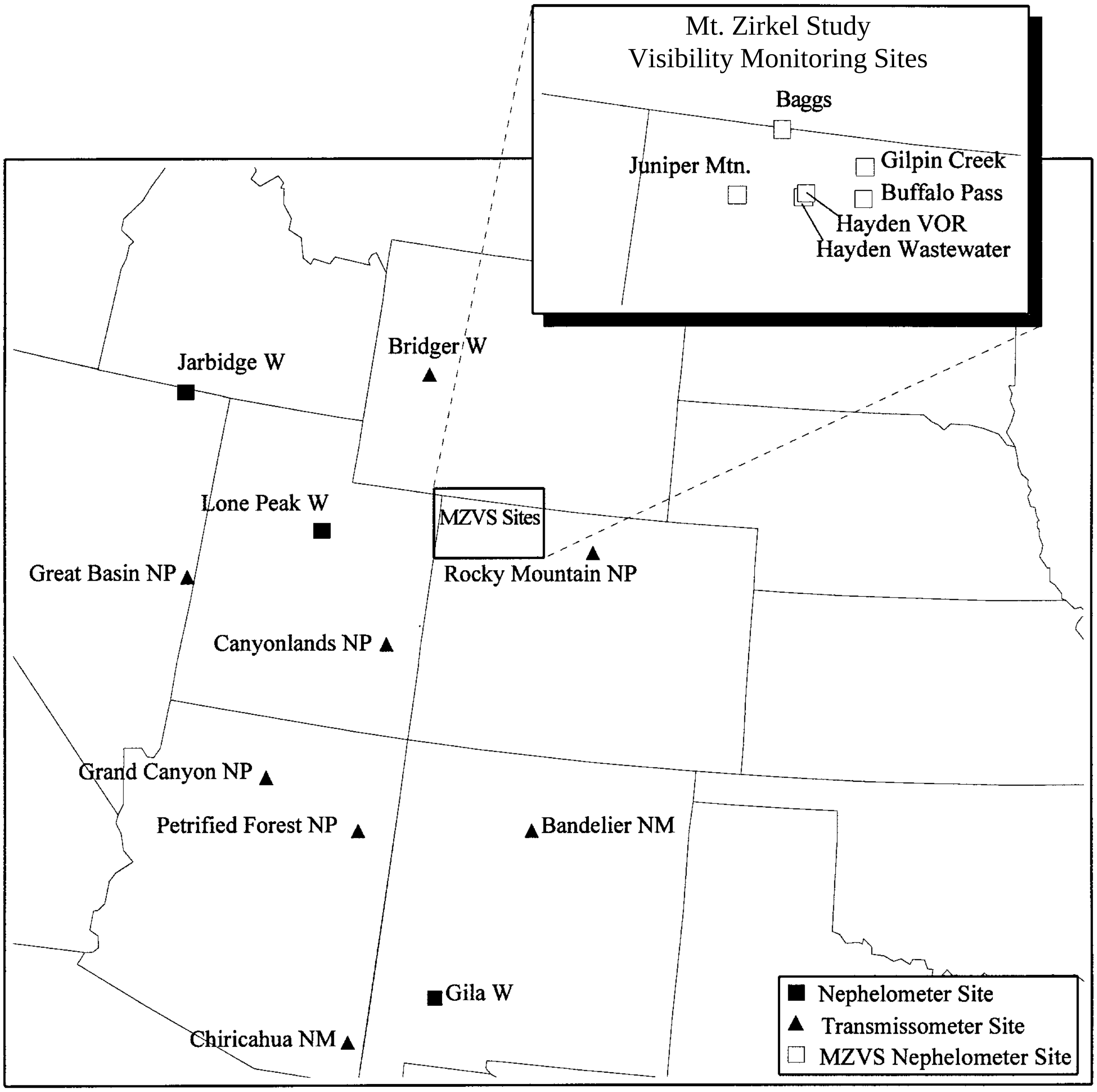


Figure 3.1.1. Locations of MZVS and IMPROVE visibility monitoring sites.

Table 3.1.1
Comparison of Mt. Zirkel Visibility Study Light Scattering with Measurements in Other Class 1 Areas

Site Name	Site Abbr.	Light scattering or extinction coefficients at 10th, 50th, and 90th percentiles (Mm^{-1})														
		Dec 1994–Nov 1995			Jan-Mar 1995			Apr-Jun 1995			Jul-Sep 1995			Oct-Nov 1995		
		10th	50th	90th	10th	50th	90th	10th	50th	90th	10th	50th	90th	10th	50th	90th
NEPHELOMETER		b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}
MZVS Sites:																
Buffalo Pass	BUPZ	10	14	22	9	11	20	11	14	23	12	16	23	9	12	17
Gilpin Creek	GLCZ	12	16	24	11	13	24	13	17	26	14	18	25	11	14	19
Juniper Mountain	JUNZ	11	16	23	9	11	18	13	16	24	14	18	25	12	15	21
Baggs	BAGZ	13	18	27	13	16	29	14	18	28	15	20	28	12	15	22
Hayden VOR	VORZ	13	18	28	12	17	27	14	18	30	15	19	28	12	15	21
Hayden Waste Water	SEWZ	15	24	43	15	27	58	16	24	37	17	24	35	13	19	32
IMPROVE and IMPROVE Protocol Sites:																
Jarbidge Wilderness	JARB	10	15	27	10	12	19	12	18	28	14	23	36	10	14	25
Lone Peak Wilderness	LOPE	12	19	35	11	15	38	15	23	35	13	20	33	13	18	36
Gila Wilderness	GILA	10	18	35	9	12	21	13	19	33	16	26	59	12	19	34
TRANSMISSOMETER		b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}
IMPROVE and IMPROVE Protocol Sites:																
Canyonlands NP	CANY	16	24	32	14	18	26	19	25	37	19	26	33	23	26	31
Grand Canyon NP South Rim	GRCA	18	26	39	18	21	28	19	26	38	26	33	43	18	24	38
Grand Canyon NP In-Canyon	GRCW	22	30	42	19	23	33	26	32	41	28	35	46	25	30	41
Bridger Wilderness	BRID	17	23	33	16	19	27	19	25	34	21	27	37	18	22	28
Rocky Mountain NP	ROMO	16	22	34	15	20	29	18	23	41	18	25	36	20	23	31
Bandelier NM	BAND	22	32	45	21	26	35	26	32	45	32	37	50	20	29	44
Petrified Forest NP	PEFO	24	37	51	15	30	40	27	37	48	34	44	56	32	39	55
Chiricahua NM	CHIR	29	42	58	27	33	44	39	37	65	40	50	69	40	42	44
Great Basin NP	GRBA	16	25	34	11	13	19	21	26	35	22	28	35	19	23	32

protocol sites. During the MZVS, the 90th percentile scattering values at the Buffalo Pass site were less than three times that of clean air, even when allowances are made for particle absorption. Only the Jarbidge Wilderness in northern Nevada is comparable to the highest light scattering measurements at these sites. The highest values at other sites are 1.5 to 2 times those measured near the Mt. Zirkel Wilderness, regardless of time of year.

At Buffalo Pass, Gilpin Creek, and Juniper Mountain, the median nonweather-related light scattering was least during the winter and highest during the summer, while at Baggs and Hayden VOR, the median nonweather-related light scattering was least during the fall and highest during the summer. At the Hayden Waste Water site adjacent to the Yampa River, the poorest median visibility values occurred during the winter months. The nearest Class I nephelometers and transmissometers exhibited the same seasonal patterns in median values as those measured at the Buffalo Pass site, with lower scattering and extinction during winter and higher values during spring and summer.

3.2 Frequencies of Observed Hazes

Time-lapse videotapes (SVHS format) were reviewed on a high-resolution monitor, and 35-mm slides were reviewed on a light table with a hand lens to assign a seven-digit scene classification code that documents conditions according to the descriptions in Table 3.2.1. Though video and 35-mm cameras are the only practical methods to record the daylight appearance of haze for later examination, they are not entirely equivalent to the scene an observer would view. The video and slide records are of restricted view and have exposure, color, and resolution limitations as compared to the human eye. An on-site observer would scan all directions horizontally and vertically and would use his or her senses and interpretive skills to assess the type and intensity of a haze. Visibility impairment is often more noticeable when viewing a scene in person than it is when viewing a time-lapse or photographic image. On the other hand, the time-lapse videos offer rapid temporal contrasts that may not register when viewed over many hours, and many of the haze events recorded during the MZVS are clearly visible in these records.

Uniform haze intensities are judged by the reduction of clarity and contrast in terrain features in a view. Since there is always some obscuration of distant targets, even in clean air, a uniform haze code of “slight” (Code 1) was assigned when a terrain feature ~60 km away was clearly visible. A uniform haze code of “moderate” (Code 2) was assigned when a terrain feature ~60 km away was difficult to discern. A uniform haze code of “considerable” (Code 3*)* was assigned when a terrain feature ~30 km away was difficult to discern. When clouds or precipitation were such that the accurate determination of the level of uniform haze intensity was impossible, the scene was coded as “weather dominates scene.”

Each scene would ideally have two easily identifiable terrain features at ~60 km and ~30 m to allow uniform haze intensity codes to be consistent between views. Scene-specific natural terrain features were based on readily visible landmarks in the view as described in Table 3.2.2. It is apparent from Table 3.2.2 that there is considerable variation in distance (± 10 km) to each of the targets, so there is variation in the absolute interpretation of these codes.

Table 3.2.1
Scene Classifications

Digit	Observed Condition Code	Description
1	SKY CONDITIONS	SKY CONDITIONS VIEWED AS CHARACTERISTIC OF THE PERIOD.
	0 No clouds	No clouds visible anywhere in the sky.
	1 Scattered clouds < half of sky	Less than one-half of the sky has clouds present.
	2 Overcast > half of sky	More than one-half of the sky has clouds present.
	3 Haze concealing scene	Atmospheric haze conditions are such that determination of the sky value is impossible.
	5 Weather dominates scene	Clouds or precipitation are such that determination of the sky value is impossible.
	8 Observation cannot be determined	Observation cannot be determined due to extreme exposure inconsistencies, lens (or window) condensation, misalignment, or view obstructed by a foreign object.
	9 No observation	No observation taken.
2	LAYERED HAZE TYPE	LAYERED HAZE TYPE OBSERVED DURING THE PERIOD.
	0 No layered haze	No layered haze boundary (intensity of coloration edge) is perceptible.
	1 Ground-based layered haze only	Only a single-layered haze boundary is perceptible with the haze layer extending to the surface.
	2 Elevated layered haze only	An elevated layered haze with two boundaries is perceptible (e.g., horizontal plume).
	3 Multiple haze layers	More than a single ground-based or elevated haze layer (or both) is perceptible.
	5 Weather dominates scene	Clouds or precipitation are such that determination of the presence of layered hazes is impossible.
	9 No observation or cannot be determined	To be used with sky condition of 9 or if a layered haze value cannot be determined due to reasons other than weather.
3	UNIFORM HAZE INTENSITY	MAXIMUM UNIFORM HAZE OBSERVED DURING THE PERIOD.
	1 Slight haze intensity	Terrain features at 60 km are clearly perceptible.
	2 Moderate haze intensity	Perception of the 60 km target is difficult to discern.
	3 Considerable haze intensity	Perception of the 30 km target is difficult to discern.
	5 Weather dominates scene	Clouds or precipitation are such that determination of the level of uniform haze intensity is impossible.
	8 Terrain features not available	To be used if terrain features at 30 km or 60 km cannot be determined.
	9 No observation or cannot be determined	To be used with sky condition code of 9 or if a uniform haze value cannot be determined due to reasons other than weather.
4	LAYERED HAZE INTENSITY	MAXIMUM LAYERED HAZE INTENSITY OBSERVED DURING THE PERIOD.
	0 No layered haze	No layered haze is perceptible.
	1 Slight layered haze	Perception of layered haze is difficult to discern.
	2 Moderate layered haze	Perception of layered haze is clearly discernable.
	3 Considerable layered haze	Perception of layered haze has such intensity that the haze appears opaque and background features are obscured.
	5 Weather dominates scene	Clouds or precipitation are such that determination of the presence of layered hazes is impossible.
	9 No observation or cannot be determined	To be used with sky condition of 9 or if a layered haze intensity value cannot be determined due to reasons other than weather.
5	VISUAL ANOMALIES	VISUAL ANOMALY SEEN DURING THE PERIOD.
	0 No anomaly	No anomaly is visible anywhere in the view.
	1 Stack emission	A stack emission is visible from either Craig or Hayden power plants.
	2 Naturally-caused smoke or fire	A smoke plume due to fire is visible.
	3 Fog	Naturally-occurring fog is clearly visible.
	4 Blowing snow	Blowing snow is visible across the entire view or part of the view.
	5 Weather dominates scene	Clouds or precipitation are such that determination of anomalous features is impossible.
	6 Blowing dust	Blowing dust or soil is visible across the entire view or part of the view.
	7 Other natural features	Any other unusual, naturally-caused feature is visible in the view.

	8 Other Man-made features	Any other unusual, man-made feature is visible in the view.
	9 No observation or cannot be determined	To be used with sky condition code of 9 or if an anomalous feature cannot be clearly identified due to reasons other than weather.

Table 3.2.1 (continued)
Scene Classifications

Digit	Observed Condition Code	Description
6	INSTRUMENT EFFECTS	PRESENCE OF WEATHER WHICH COULD EFFECT THE INSTRUMENTS DURING THE PERIOD.
	0 No effect	No apparent weather related effects on visibility or aerosol instruments at monitoring sites within the view or collocated with the camera.
	1 Weather effects	Probable weather related effects on visibility or aerosol instruments at monitoring sites within the view.
	5 Weather dominates scene	Clouds or precipitation are such that determination of instrument effects are impossible.
	8 N/A	No aerosol or visibility monitoring sites in view.
	9 No observation or cannot be determined	To be used with sky condition code of 9 or if scene features cannot be clearly identified due to reasons other than weather.
7	STACK/COOLING TOWER PLUME DYNAMICS	STACK OR COOLING TOWER DYNAMICS WHICH CHARACTERIZE THE PERIOD.
	0 No plume	No steam or other emissions are visible.
	1 Up valley - decoupled	Observed steam plumes or stack emissions generally flow up valley but either plume dynamics or observed plume and cloud motions indicate a decoupling of air flows in the scene.
	2 Down valley - decoupled	Observed steam plumes or stack emissions generally flow down valley but either plume dynamics or observed plume and cloud motions indicate a decoupling of air flows in the scene.
	3 Up valley - coupled	Observed steam plumes or stack emissions generally flow up valley but neither plume dynamics nor observed plume or cloud motions indicate any flow decoupling.
	4 Down valley - coupled	Observed steam plumes or stack emissions generally flow down valley but neither plume dynamics nor observed plume or cloud motions indicate any flow decoupling.
	5 Weather dominates scene	Clouds or precipitation are such that determination of plume features is impossible.
	6 Vertical plume	Observed steam or stack emissions rise vertically; no dominant direction observed, decoupling may or may not be present.
	7 Other	Observed steam plumes or stack emissions have characteristics that cannot be described by any of the above codes.
	8 N/A	Power plant not in the view.
	9 No observation or cannot be determined	To be used with sky condition code of 9 or if plume features cannot be clearly identified due to reasons other than weather.

Table 3.2.2
Criteria for Determining Uniform Haze Intensities for the Mt. Zirkel Visibility Study

Relative Haze Intensity Code

Site	Slight [1]		Moderate [2]		Considerable [3]	
	Referenced Topographic Feature	Approx. Distance	Referenced Topographic Feature	Approx. Distance	Referenced Topographic Feature	Approx. Distance
Storm Peak - Hahns Peak	Hahns Peak	60 km	Hahns Peak	60 km	End of valley floor	30 km
Storm Peak - Yampa Valley	Elkhead Mtns.	60 km	Elkhead Mtns.	60 km	Wolf Mtn.	30 km
Buffalo Pass	Medicine Bow Mtns.	50 km	Medicine Bow Mtns.	50 km	Sheep Mtn.	29 km
Gilpin Creek	N/A	N/A	N/A	N/A	Pilot Knob	37 km
Chavez Mountain - Buffalo Pass View	Mt. Zirkel	55 km	Mt. Zirkel	55 km	Rocky Peak	30 km
Chavez Mountain - Zirkel View	Mt. Zirkel	55 km	Mt. Zirkel	55 km	Pilot Knob	30 km
Chavez Mountain - Hayden View	Black Mtn.	50 km	Black Mtn.	50 km	Agner Mtn.	30 km
Cedar Mountain	Pyramid Peak	55 km	Pyramid Peak	55 km	Wilson Mesa	40 km
Juniper Mountain - East View	Pagoda Peak	60 km	Pagoda Peak	60 km	Cedar Mtn.	35 km
Juniper Mountain - North View	Bakers Peak	65 km	Bakers Peak	65 km	Big Gulch Rim	30 km
Juniper Mountain - West View	Tanks Peak	60 km	Tanks Peak	60 km	Cross Mtn.	30 km
Juniper Mountain - South View	N/A	N/A	N/A	N/A	Colorow Mtn.	28 km

[1] Slight haze intensity-Terrain features at 60 km are clearly perceptible.
[2] Moderate haze intensity-Perception of the 60 km target is difficult to discern.
[3] Considerable haze intensity-Perception of the 30 km target is difficult to discern.

When the time-lapse images were viewed to evaluate uniform or layered hazes, the worst-case condition that could be clearly identified during the nominal 0600 to 1200 MST (a.m.) and 1200 to 1800 MST (p.m.) periods was recorded. The actual classification period extended from sunrise to sunset, which was slightly longer or shorter than these intervals depending on the time of year. When a moderate layered haze was observed for one hour during the early morning, but the layer dissipated as the morning progressed, the morning was assigned the code for a moderate layered haze. This code was given even though the major fraction of the period might correspond to a slight uniform haze in order to call attention to the time and location of such a haze.

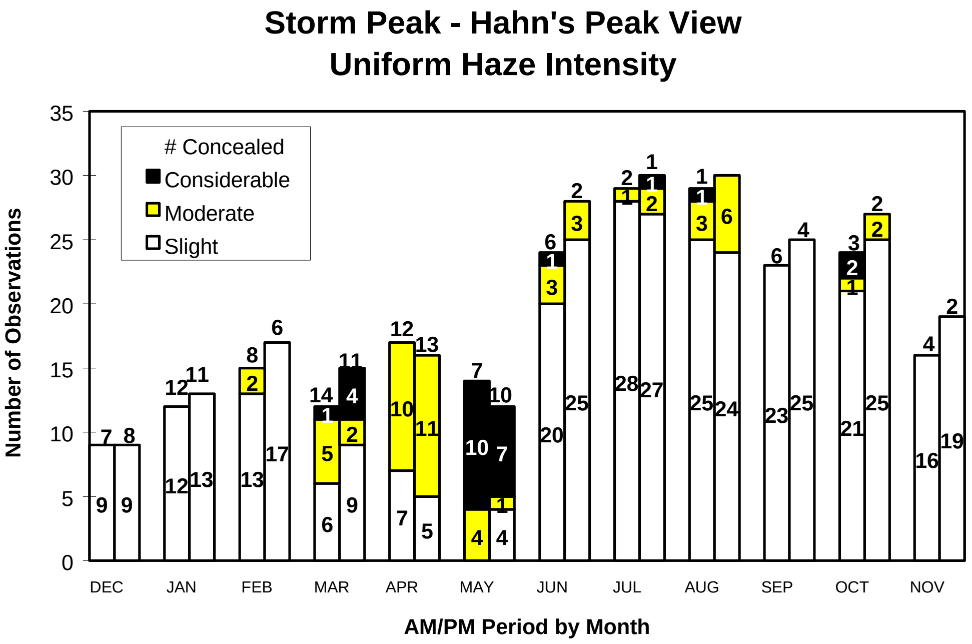
Still photographs were not as useful as videos for classification because they represent an instantaneous record of conditions observed at 0900, 1200, and 1500 MST rather than a continuous evolution of visibility events. Slide and video classifications of the same view do not necessarily match. For example, a haze layer observed on a video between sunrise and 0800 that dissipated by 0830 would not be observed on a corresponding 0900 35-mm slide.

The assigned uniform haze code is partially indeterminate for the Gilpin Creek (GLCZ) and Juniper Mountain south (JUNS) view because prominent landmarks could not be seen at or near the 60 km or 30 km distances. For example, for the Juniper Mountain south view, a uniform haze code of 8 means that the 30 km feature was clearly visible, but there is no way to classify a view beyond this distance. A uniform haze code of 8 was used where this situation occurred, and results are represented by N/A in Table 3.2.2.

The result of this coding process is a digital file for each site in the MZVS data base that contains a seven-digit code for each slide or each half-day of videotape. These classifications can only be used to document the presence of observed conditions, and in some cases the sources of those conditions. Several of the layered hazes, for example, could be directly attributed to excessive primary particle emissions from a power generating station during a malfunction or to a prescribed burn. For most situations, however, the videos and 35-mm slides could not identify the source of a haze, especially uniform hazes, nor could they determine the chemical composition or full spatial extent of that haze. Naturally-occurring fogs and clouds along sight paths, as well as manmade pollution, could be the reasons that distant targets were obscured, but these causes must be determined by other aspects of the MZVS.

To illustrate how these classification codes appear visually, an abbreviated VHS video has been prepared as part of the MZVS data base, with examples of each time-lapse video view shown in Figure 2.1.2; slight, moderate, and considerable hazes; primary source emissions; and the appearance of haze under different illumination and weather conditions.

Detailed plots of haze classifications are contained in quarterly data reports (Air Resource Specialists, 1995). Figures 3.2.1 through 3.2.4 summarize by month the number of slight, moderate, and considerable hazes observed for uniform and layered situations excluding those concealed by poor weather. The Storm Peak views of Hahns Peak and the Yampa Valley represent views that can be seen from the Mt. Zirkel Wilderness. The


Storm Peak - Hahn's Peak View
Uniform Haze Intensity

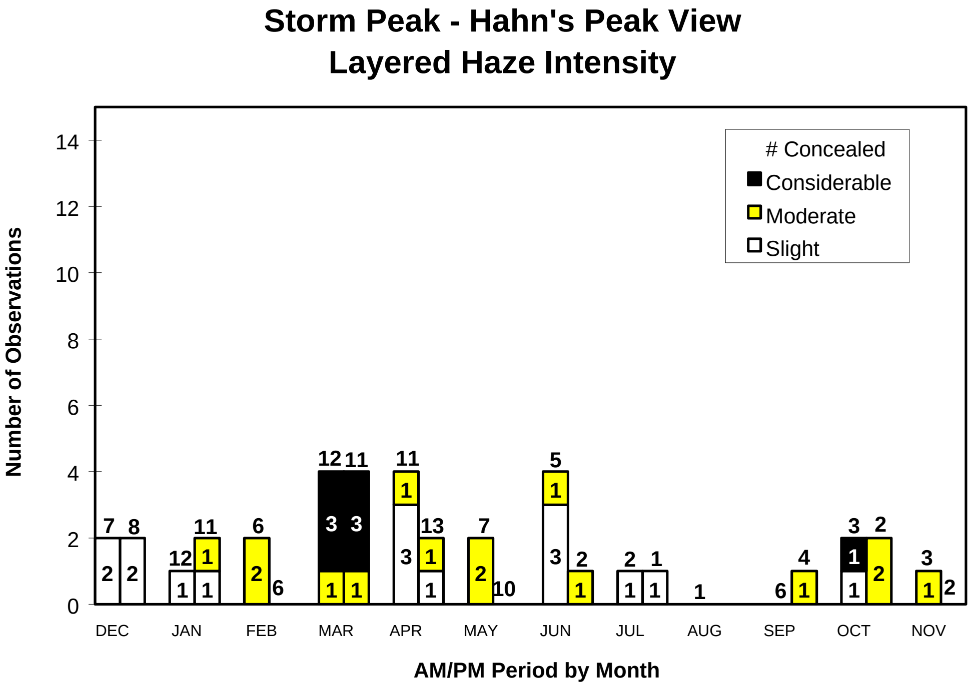

Storm Peak - Hahn's Peak View
Layered Haze Intensity

Figure 3.2.1. Observation frequencies of slight, moderate, and considerable uniform and layered hazes in the Hahns Peak video view from Storm Peak.

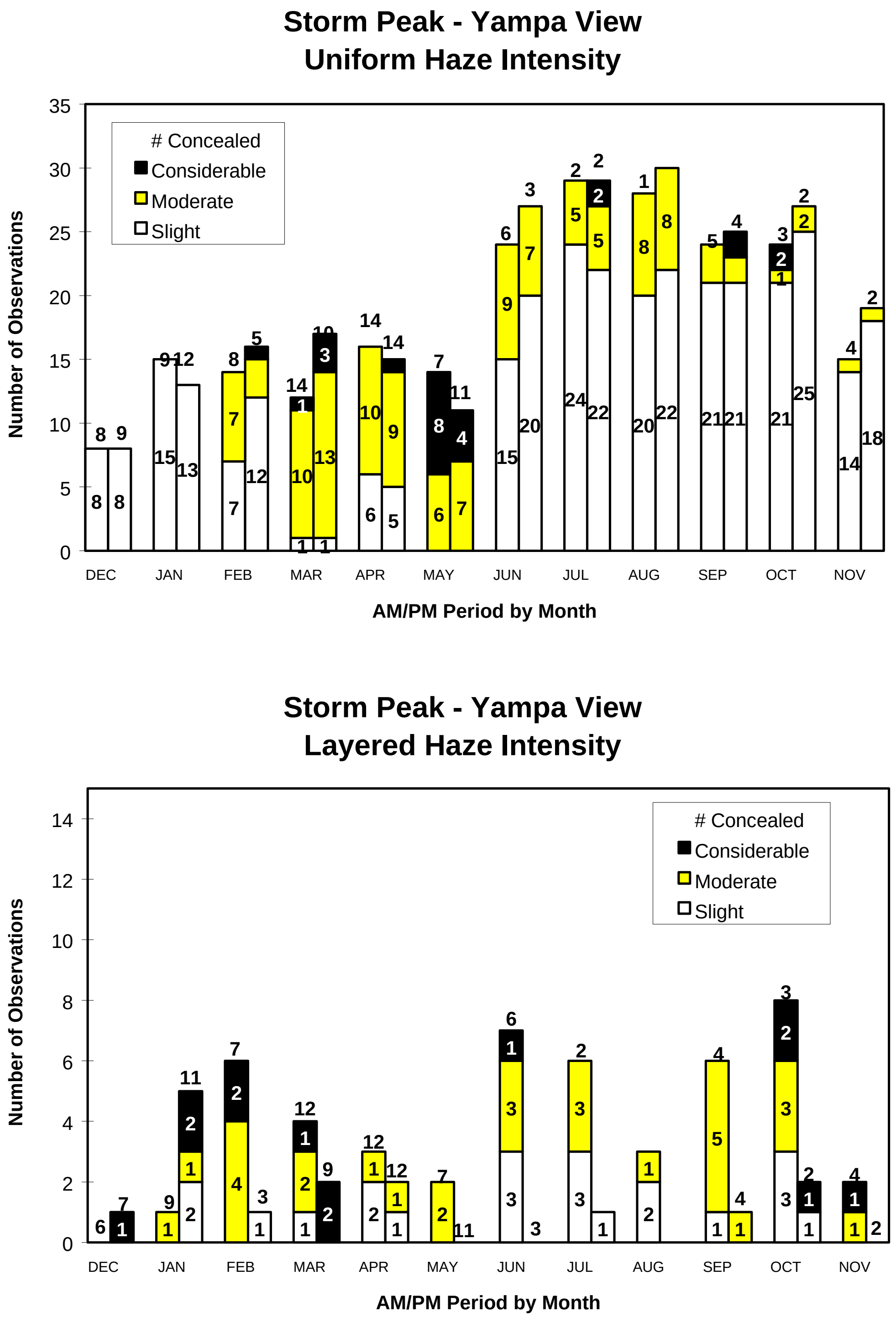
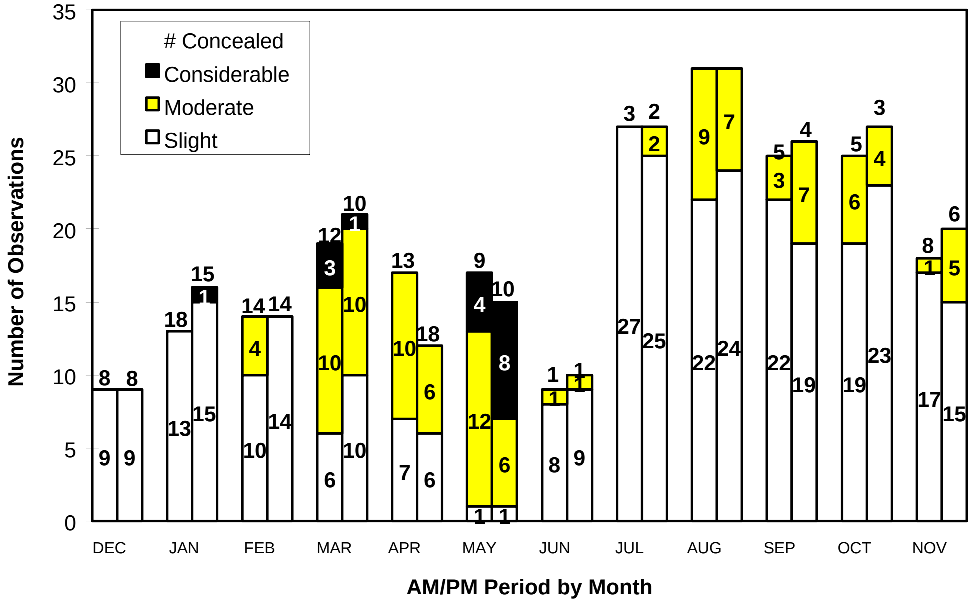
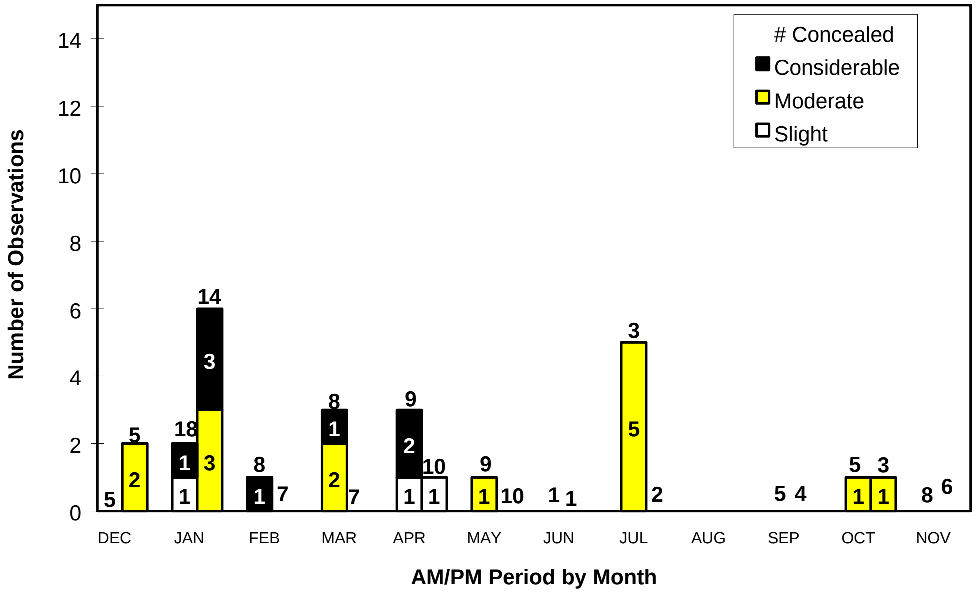


Figure 3.2.2 Observation frequencies of slight, moderate, and considerable uniform and layered hazes in the Yampa Valley video view from Storm Peak.

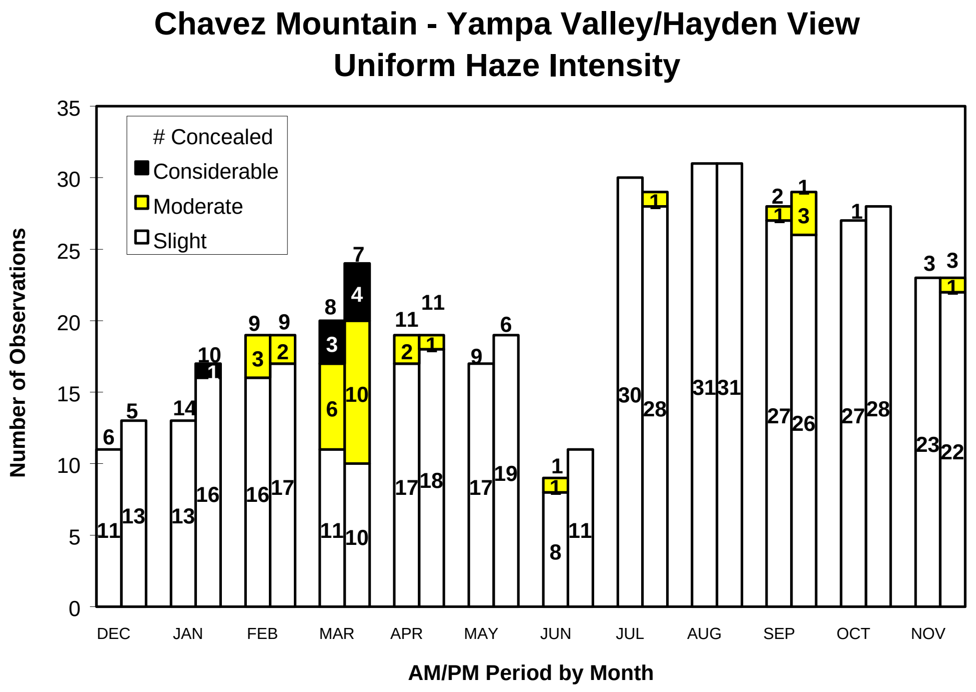


Chavez Mountain - Mt. Zirkel View
Uniform Haze Intensity



Chavez Mountain - Mt. Zirkel View
Layered Haze Intensity

Figure 3.2.3 Observation frequencies of slight, moderate, and considerable uniform and layered hazes in the Mt. Zirkel video view from Chavez Mt.


Chavez Mountain - Yampa Valley/Hayden View
Uniform Haze Intensity

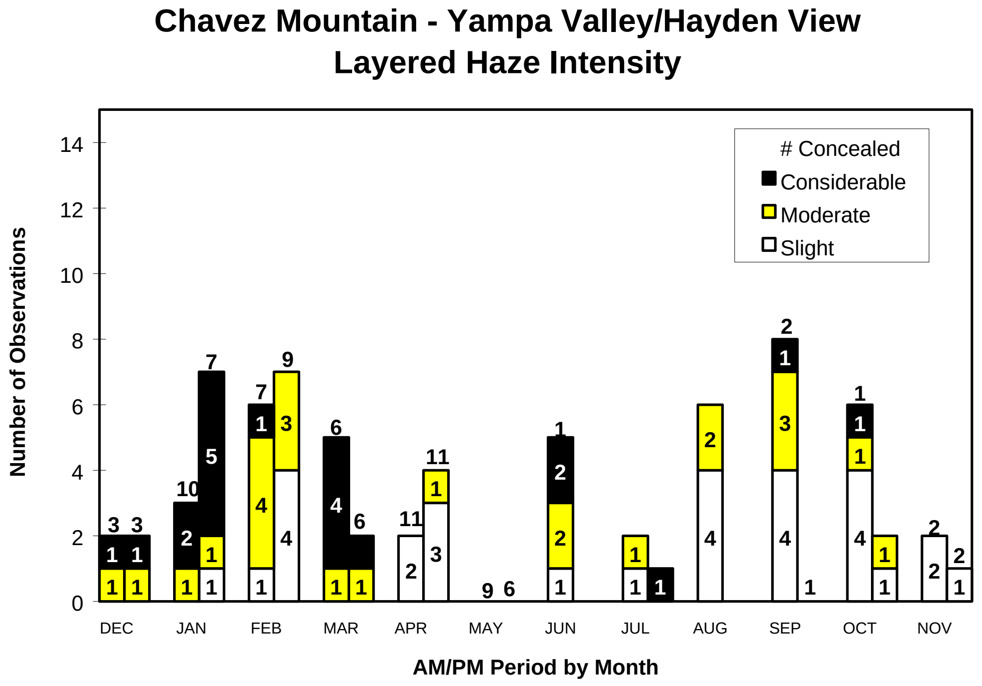

Chavez Mountain - Yampa Valley/Hayden View
Layered Haze Intensity

Figure 3.2.4 Observation frequencies of slight, moderate, and considerable uniform and layered hazes in the Hayden video view of the Yampa Valley from Chavez Mt.

Chavez Mountain views of Mt. Zirkel and the Hayden Generating Station represent what can be seen from within the Yampa Valley. Each view is different and incorporates different terrain features, lighting conditions, and viewing angles. What can be seen from one site may not be visible from another, or the scene may look considerably different.

Weather commonly concealed the views during the winter and spring months, particularly at the higher elevation Storm Peak site. Weather-concealed classifications decreased in June when wetter winter and spring storm patterns shifted to drier summer patterns. Sight paths for the Chavez video views across the Yampa Valley and toward Mt. Zirkel often included morning pollutant accumulations in the valley, and uniform haze classifications for these views tend toward the moderate and considerable categories.

3.2.1 Uniform Haze

The frequencies shown in Figures 3.2.1 through 3.2.4 indicate that slight uniform hazes were observed most of the time during all but the spring months. As noted in Section 2.2, March, April, and May contained an unsettled period with numerous storms. Classifications during this period were difficult owing to the extreme weather. Many of the codes could be influenced by precipitation events, clouds, or unusual lighting along the sight path that might obscure distant targets. Views were commonly limited to several hours a day as precipitation ebbed and clouds lifted, especially during May. A number of considerable hazes were noted for all views in May except for the Chavez Mountain view of Hayden.

No moderate or considerable uniform hazes were observed from Storm Peak during December, January, September, and November. Views from the Yampa Valley sites contained several occurrences of moderate and considerable hazes, but the slight category was most prevalent. Slight hazes were most often observed during July and August for all views. Data recovery from the Chavez Mountain videos was limited during June owing to a lightning strike that disabled the monitoring equipment.

During the winter (February) Intensive Operating Period (IOP), moderate uniform hazes were observed in the Storm Peak/Hahns Peak view during the morning periods on 02/07/95 and 02/28/95. Moderate hazes were observed in the Storm Peak/Yampa view during the morning periods on 02/05/95, 02/07/95, 02/19/95, 02/21/95, 02/22/95, 02/23/95, and 02/25/95, and during the afternoon periods on 02/19/95, 02/21/95, and 02/23/95. One considerable haze was observed in the Yampa view during the afternoon on 02/28/95. The Storm Peak views exhibited patterns similar to those in views from the Yampa Valley sites (CHBZ, CHZZ, and CHHZ) on 02/07/95, 02/21/95, 02/22/95, 02/23/95, and 02/28/95. These observations indicate that a range of uniform haze conditions occurred during the winter IOP.

During the summer (August) IOP, slight uniform hazes dominated all views, but most views observed moderate hazes more often during August than during any other summer or fall month. Considerable hazes were seldom observed. High elevation and Yampa Valley views exhibited similar patterns. Events of moderate uniform haze were observed on 08/08/95, 08/11/95, and 08/20/95 through 08/24/95, from both the high elevation and the Yampa Valley sites.

During the fall (mid-September to mid-October) IOP, slight uniform hazes were seen most of the time, but moderate and considerable uniform hazes were sometimes observed from all sites, specifically on 09/18/95, 09/19/95, 09/24/95, 10/01/95, 10/02/95, 10/08/95, and 10/12/95.

3.2.2 Layered Haze

Layered hazes were not seen as often as uniform hazes, but they were observed throughout the year in one or more of the views. The maximum number of layered hazes observed from any site during any month was nine and the minimum was zero. Generally the number of slight, moderate, and considerable layered haze intensities were the same. No intensity level was dominant. Layered hazes were observed many more times during the "a.m." period than the "p.m." period, particularly in the summer months.

For the Storm Peak views, layered haze occurrences were evenly distributed throughout the year. Considerable layered hazes were observed most often during cold months. On several occasions in late December and January, layered hazes observed in the Yampa Valley could be visually traced to visible plumes of primary particles from the Hayden Station. These events are described in Section 5.5. No considerable hazes were found during July, August, or September. Layered hazes were most often identified in the Storm Peak/Yampa view (STPY), owing to its elevation, broad vistas, and solar orientation. For this view, winter and fall IOPs experienced the highest frequencies of moderate and considerable haze layers.

Slight layered hazes were not easily discerned from the Chavez Mountain view of Mt. Zirkel; therefore, moderate and considerable hazes were recorded more frequently. Very few layered hazes were observed from the CHZZ view during the summer months.

The Chavez Mountain view of Hayden included the Hayden Station, and layers observed in the view were commonly associated with its emissions. Layers occurred more often in the "a.m." period, but layers were also observed in the "p.m." period particularly during January and February.

These observations show that visibility is very good near the Mt. Zirkel Wilderness area most of the time. Most of the observed hazes were uniform with no defined edge. Layered hazes were most commonly observed during the morning, and along sight paths through the Yampa Valley. Uniform and layered hazes were observed during the winter, summer, and fall IOPs.

3.3 Frequencies of Light Scattering in the MZVS

Frequency distributions of light scattering values for each OPTEC nephelometer in the network were calculated for those hours when the relative humidity was < 95% and the data were not flagged for weather interference. The 25th, 50th, and 75th percentiles of total light scattering for each site for each month are shown in Figure 3.3.1. These plots elaborate on the percentiles in Table 3.1.1 by providing: 1) percentiles for each month of the study; 2) maximum and minimum scattering, as well as percentiles; and 3) a less exclusive relative humidity screen of 95%.

Consistent with the comparisons in Table 3.1.1, light scattering at Buffalo Pass, Gilpin Creek, and Juniper Mountain were the lowest observed at any of the sites with respect to 50th and 80th percentiles as well as the hourly maxima. This was the case for each month of the study. The highest hourly light scattering value of 59 Mm^{-1} was found at the Buffalo Pass site during June, with the highest value of 61 Mm^{-1} found at the Gilpin Creek site in March. The Baggs, Hayden VOR, and Hayden Waste Water sites experienced maximum hourly scattering values of ~60 Mm^{-1} during most of the months, and their 50th and 75th percentile values were commonly larger that the corresponding percentiles at Buffalo Pass, Gilpin Creek, and Juniper Mountain

The variability of light scattering between sites was highest during the winter when Buffalo Pass showed the lowest light scattering and Hayden Waste Water showed the highest scattering. During the winter, the lowest 25% of the light scattering at Buffalo Pass, Gilpin Creek, and Juniper Mountain were very close to the clean air scattering values; Baggs and Hayden VOR light scattering were ~50% larger than clean air scattering, and light scattering at Hayden Waste Water was approximately double that of clean air. The high Hayden Waste Water scattering compared to the lower regional background values implies that Yampa Valley particle sources had a large impact at that site during winter.

During the summer, light scattering at Buffalo Pass, Gilpin Creek, Juniper Mountain, Baggs, and Hayden VOR were all higher compared to their winter values or to clean air scattering. Hayden Waste Water experienced a decrease in light scattering between the winter and summer. During summer, the light scattering frequencies for the different sites were more similar to each other than during the winter.

During the fall, light scattering at all sites was lower than during the summer. Hayden Waste Water and Hayden VOR achieved their lowest values of the year, with minima that were ~4 Mm^{-1} larger than clean air scattering. The other four sites experienced values equal to, or slightly larger than, their winter values.

Non-weather light scattering during the IOPs, indicated by heavy dark lines at the bottom of Figure 3.3.1, showed the frequencies of different light scattering levels to be similar to, or slightly larger than, values seen in other months related to the winter, summer, and fall. The intensive operating periods were representative of the variations of total light scattering observed over their seasons.

Minimum, Maximum, 25th, 50th, and 75th Percentiles of Total Light Scattering
(12/1/94-11/30/95)

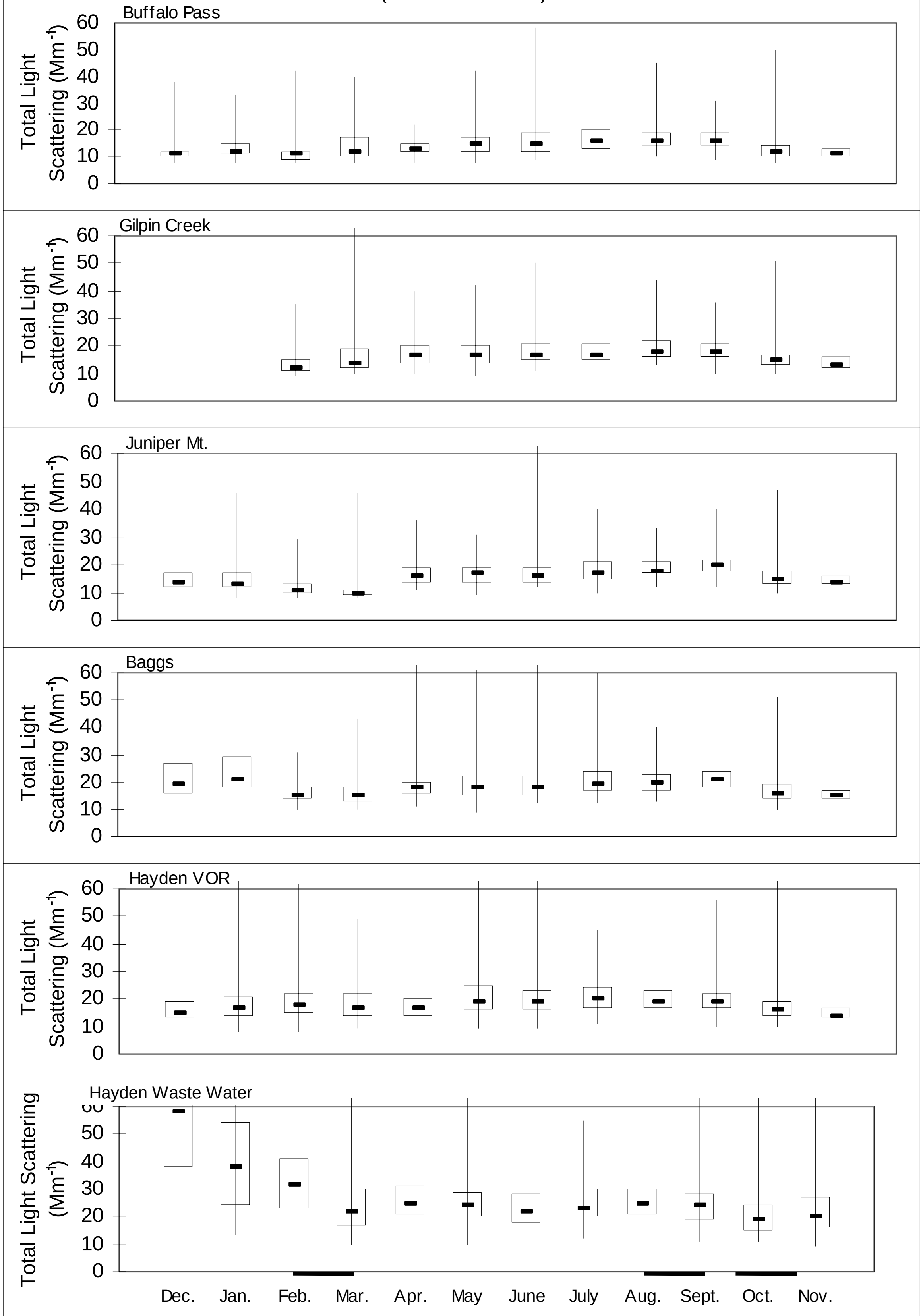


Figure 3.3.1. The monthly variation in total light scattering at all sites (RH < 95%). The heavy lines at the bottom indicate the intensive operating periods

Table 3.1.1
Comparison of Mt. Zirkel Visibility Study Light Scattering with Measurements in Other Class 1 Areas

Site Name	Site Abbr.	Light scattering or extinction coefficients at 10th, 50th, and 90th percentiles (Mm^{-1})														
		Dec 1994–Nov 1995			Jan-Mar 1995			Apr-Jun 1995			Jul-Sep 1995			Oct-Nov 1995		
		10th	50th	90th	10th	50th	90th	10th	50th	90th	10th	50th	90th	10th	50th	90th
NEPHELOMETER		b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}	b_{scat}
MZVS Sites:																
Buffalo Pass	BUPZ	10	14	22	9	11	20	11	14	23	12	16	23	9	12	17
Gilpin Creek	GLCZ	12	16	24	11	13	24	13	17	26	14	18	25	11	14	19
Juniper Mountain	JUNZ	11	16	23	9	11	18	13	16	24	14	18	25	12	15	21
Baggs	BAGZ	13	18	27	13	16	29	14	18	28	15	20	28	12	15	22
Hayden VOR	VORZ	13	18	28	12	17	27	14	18	30	15	19	28	12	15	21
Hayden Waste Water	SEWZ	15	24	43	15	27	58	16	24	37	17	24	35	13	19	32
IMPROVE and IMPROVE Protocol Sites:																
Jarbidge Wilderness	JARB	10	15	27	10	12	19	12	18	28	14	23	36	10	14	25
Lone Peak Wilderness	LOPE	12	19	35	11	15	38	15	23	35	13	20	33	13	18	36
Gila Wilderness	GILA	10	18	35	9	12	21	13	19	33	16	26	59	12	19	34
TRANSMISSOMETER		b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}	b_{ext}
IMPROVE and IMPROVE Protocol Sites:																
Canyonlands NP	CANY	16	24	32	14	18	26	19	25	37	19	26	33	23	26	31
Grand Canyon NP South Rim	GRCA	18	26	39	18	21	28	19	26	38	26	33	43	18	24	38

Grand Canyon NP In-Canyon	GRCW	22	30	42	19	23	33	26	32	41	28	35	46	25	30	41
Bridger Wilderness	BRID	17	23	33	16	19	27	19	25	34	21	27	37	18	22	28
Rocky Mountain NP	ROMO	16	22	34	15	20	29	18	23	41	18	25	36	20	23	31
Bandelier NM	BAND	22	32	45	21	26	35	26	32	45	32	37	50	20	29	44
Petrified Forest NP	PEFO	24	37	51	15	30	40	27	37	48	34	44	56	32	39	55
Chiricahua NM	CHIR	29	42	58	27	33	44	39	37	65	40	50	69	40	42	44
Great Basin NP	GRBA	16	25	34	11	13	19	21	26	35	22	28	35	19	23	32

3.4 Visibility Episodes

Figure 3.4.1 documents hourly light scattering from clean air and suspended particles at each site for the entire MZVS measurement period. These plots were used as the primary method of identifying visibility episodes, and events within those episodes. Aerosol filter samples corresponding to these episodes were chemically analyzed, and five of them were examined with detailed data analysis and modeling.

Figure 3.4.1 includes light scattering measured with the OPTEC nephelometer, with values corresponding to RH<90% plotted with a heavy line and values corresponding to RH>90% plotted with a thin line; RH values are plotted with a dotted line. No data are plotted for periods of missing or invalid measurements. Many of the light scattering readings exceed the graphical scale when RH>90%, indicating the presence of fogs or clouds that dominated the light scattering measurement. These events are confirmed most of the time by collocated photographs and videos that show the sight path to be completely obscured at these high relative humidities.

Figure 3.4.1 shows substantial obscuration due to weather from December through May, especially at the Buffalo Pass and Gilpin Creek sites. Many, but not all, of these weather events occurred simultaneously at all sites during winter and spring, indicating the widespread and frequent storms discussed in Section 2.2. The unusual frequency of storms during May that was identified in Section 2.2 is clearly evident in the nephelometer traces for that month. There were very few periods during which visibility was not obscured by storm clouds, and these were commonly of short duration. Fogs and clouds near the sampling sites were more spatially diverse during summer and fall, however, and occurred more frequently at the Buffalo and Gilpin Creek sites than at the other sites.

For much of the time when clouds or fogs did not dominate extinction, the nephelometer traces at Buffalo Pass, Gilpin Creek, and Juniper Mountain were at or near the clean air scattering limit of ~10 Mm^{-1}, consistent with the frequency distributions in Table 3.1.1 and Figure 3.3.1. Hour-to-hour excursions in light scattering are often abrupt, and they often rise and fall in conjunction with RH. This was especially true when RH varied between ~60% and 90%. This covariation is consistent with major components of the suspended particles being water soluble, and growing into size ranges that scatter light more efficiently when they extract water from a humid atmosphere. It is also consistent with the formation of aerosol sulfate in clouds which are often present at high humidity.

In addition to these plots, $PM_{2.5}$ mass concentrations and continuous sulfur dioxide and light absorption measurements at Buffalo Pass were examined to select visibility episodes for more detailed analysis. Tabulations of wildfire acreage available through September 1995 were also used to ensure that some episodes included and excluded major wildfire activity. These sample analysis periods are designated in Figure 3.4.1 by solid bars corresponding to the 0600 to 1800 MST daylight period during which aerosol samples were taken. They fulfill one or more of the following criteria delineated by Watson *et al.* (1995) for sample selection:

- Visibility is Impaired: Nonweather-related light scattering increased, as indicated by the OPTEC nephelometer traces.

- Visibility is Not Impaired: These are events with some elevated scattering and $PM_{2.5}$ mass, but not obvious or considerable hazes. These were usually selected from samples before or after events when light scattering was high.

- Plume Transport to Receptors. Plume transport was identified from continuous sulfur dioxide and light absorption measurements at Buffalo Pass. Some cases of plume transport to the Hayden VOR site were identified from videos.

- Specific Atmospheric and Emissions Conditions: These events include: 1) samples for which there is evidence of direct plume impact without major traversal of complex terrain (e.g., impacts at Waste Water and VOR); 2) evidence of direct plume impact with traversal of complex terrain (e.g., impacts at Juniper Mountain and Buffalo Pass); 3) long-range transport from distant sources (e.g., fires or haze from outside of the Yampa Valley); 4) mixing of plumes in clouds; and 5) plume accumulation in the Valley during nighttime and early morning and subsequent upslope transport. These events were chosen using videos, relative humidity data, and the everyday plume model animation discussed in Section 5.4 (which shows the plume transport direction).

- Measurements Evaluation: Sulfur dioxide and sulfate filter samples at Buffalo Pass were selected to compare with elevated sulfur levels measured with the continuous monitors. Organic and elemental carbon samples at Buffalo Pass were selected to compare with elevated light absorption levels measured with the continuous monitors. Aerosol samples were selected for which the $PM_{2.5}$ mass concentrations were much higher than those measured at other sampling sites.

The following episodes resulted from this selection criteria.

- 02/23/95: Figure 3.4.1 shows an increase in the Buffalo Pass light scattering during an IOP. This was accompanied by a sharp 22 ppb spike of sulfur dioxide with low black carbon concentrations. Conditions were moist, especially at higher elevations. This was the only nonweather light scattering excursion near the Wilderness that was observed during the winter IOP.

- 03/26/95–03/31/95: Light scattering was elevated at all sites during this non-IOP, indicating a regionwide event. Videos showed weather obscuration, punctuated by cloud clearing during which distant targets were moderately obscured. A 20-ppb sulfur dioxide spike occurred at Buffalo Pass on the morning of 03/30/95, but visibility was obscured by weather at this time. A morning scattering spike on 03/28/95 was not accompanied by an sulfur dioxide levels. Conditions were moist throughout the region.

- 05/06/95–05/07/95: Light scattering was elevated at all sites during this non-IOP, achieving ~30 Mm^{-1} at Buffalo Pass and Gilpin Creek. Sulfur dioxide was not available at Buffalo Pass. Conditions were moist, with weather obscuration at Buffalo Pass and Gilpin Creek.

- 06/14/95–06/16/95: A consistently high scattering of ~30 to 40 Mm^{-1} was recorded throughout the network during this dry, non-IOP period, indicating a regionwide event. Sulfur dioxide measurements were not available at Buffalo Pass.

- 06/29/95–07/01/95: Scattering coefficients of ~40 to 60 Mm^{-1} were recorded at Juniper and Baggs, on 06/30/95, with rapid decrease on 7/1 during this non-IOP period. Scattering at Buffalo Pass and Gilpin Creek was ~30 Mm^{-1} over this period, which was accompanied by clouds or fog at Buffalo Pass. The other sites experienced lower relative humidity, ~50% to 80%, during daylight hours.

- 07/29/95–07/31/95: Scattering was elevated at all sites, approaching 30 Mm^{-1} at Buffalo Pass, during this non-IOP, low humidity period. Scattering was variable from hour to hour at all sites.

- 08/07/95–08/09/95: Scattering increased over previous days to values exceeding 30 Mm^{-1} at Buffalo Pass during this IOP. Relative humidity was commonly low (RH <50%) at all sites during daylight hours.

- 08/14/95: This day was typical of most of the days during the August IOP, and was selected to represent them. A small scattering increase occurred at Buffalo Pass in the morning, coincident with an increase in sulfur dioxide.

- 08/21/95–08/27/95: This is an IOP example of high relative humidity conditions followed by a period of lower relative humidities. Light scattering ranged from ~20 to ~40 Mm^{-1} at Gilpin Creek during this period, with substantial hour-to-hour variability. There was a marked correspondence between light scattering and relative humidity at Hayden VOR and Hayden Waste Water. The latter half of the period was included to examine a relatively clean period for comparison.

- 09/02/95: An increase in light scattering at Buffalo Pass was partially accompanied by an increase in sulfur dioxide during this IOP period.

- 09/17/95–09/21/95: This IOP episode commenced with low relative humidities, increasing to RH>90% with accompanying increases in scattering. Weather commonly obscured views of the Wilderness during this episode. Several correspondences between excursions in light scattering and sulfur dioxide concentrations were measured at Buffalo Pass.

- 09/24/95: This IOP episode experienced morning peaks in light scattering at most of the sites and a distinct peak in light scattering during the late afternoon at Gilpin Creek.

- 09/27/95: This was a dry IOP episode with correspondence between light scattering and sulfur dioxide. Two light scattering spikes were recorded at most of the sites.

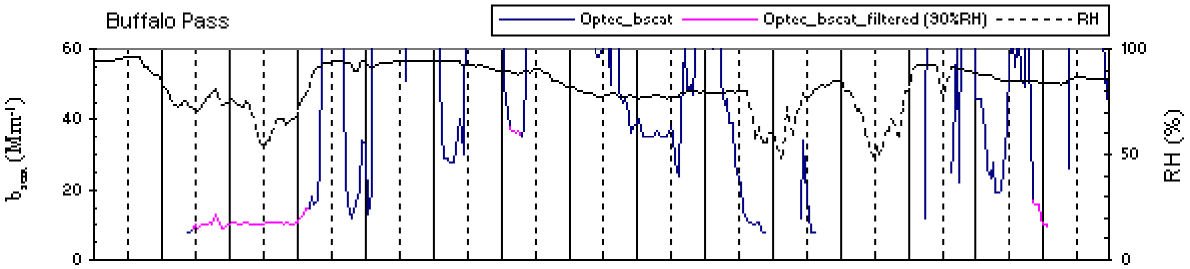
- <u>09/30/95–10/02/95:</u> Light scattering was elevated throughout the network during this IOP event. Relative humidity decreased from >90% to <50% during the afternoon during the latter part of this episode. Changes in light scattering were accompanied by changes in sulfur dioxide concentrations on 10/01/95.

- <u>10/07/95–10/14/95</u>: This episode is important because a wide variety of conditions were observed. The light scattering was elevated at all of the sites from the 10/07/95 through the 10/12/95 and then dropped to near Rayleigh on 10/13/95 and 10/14/95. There were two large peaks (10/08/95 and 10/12/95) in light scattering superimposed on the elevated light scattering and corresponding to peaks in the relative humidity. Also during this elevated period there were intermittent spikes of sulfur dioxide at Buffalo Pass. The 10/13/95 and 10/14/95 dates were of interest because the light scattering was very low while there were high sulfur dioxide concentrations present at Buffalo Pass. This is one of the primary episodes for modeling.

- <u>10/16/95–10/19/95</u>: There was elevated light scattering throughout the network that decreased toward 10/19/95 at all sites except Buffalo Pass and Gilpin Creek, which showed peaks in their light scattering. A prescribed burn was seen in the 10/19/95 video of the Yampa Valley from Cedar Mountain.

- <u>10/22/95–10/23/95</u>: There was high relative humidity throughout the region and large peaks in light scattering at several of the sites. There were coincident sulfur dioxide and light-scattering peaks on 10/23/95 at Buffalo Pass.

All of the episodes listed above were subjected to full chemical analyses of aerosol samples and ELSIE and CMB modeling. In addition, five of these episodes (08/07/95–08/09/95, 08/21/95–08/27/95, 09/17/95–09/21/95, 10/07/95–10/14/95, and 10/16/95–10/19/95) were submitted to more detailed data analysis and CALMET/CALPUFF modeling. These five episodes represent a range of meteorological and emissions conditions that can be compared and contrasted with each other. Other episodes listed above contain meteorological situations that are similar, though not identical, to these five episodes. Of the entire 54 days identified as visibility episodes, these modeled periods include 29 of those days, and the majority of those that occurred during the IOPs. In addition to the periods modeled, the 09/27/95 episode was examined in more detail since it represented one of the few times when b_{scat} and sulfur dioxide had corresponding peaks during dry conditions.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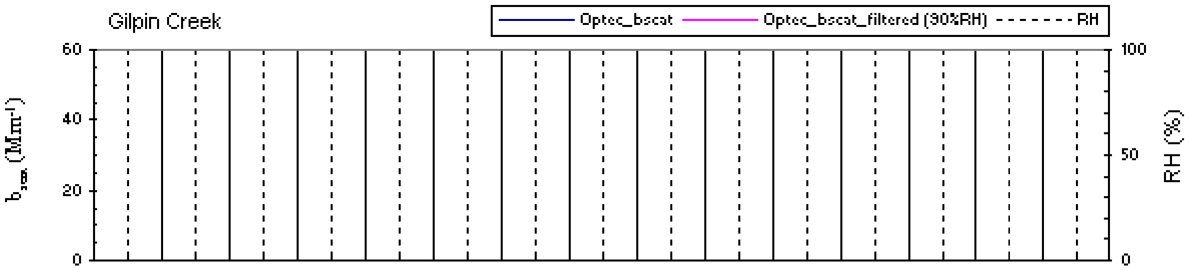
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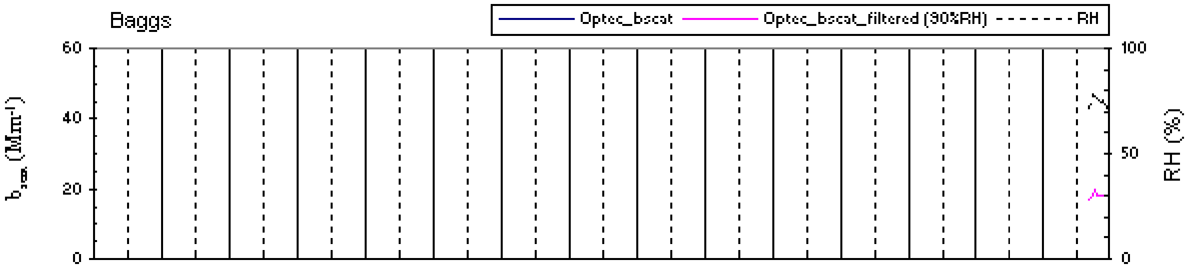
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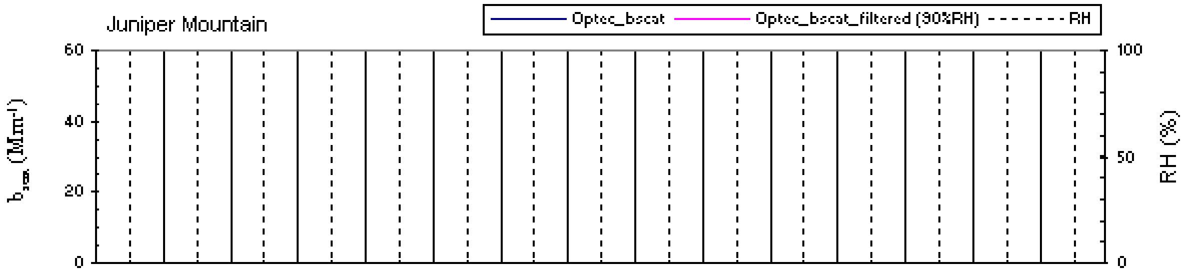
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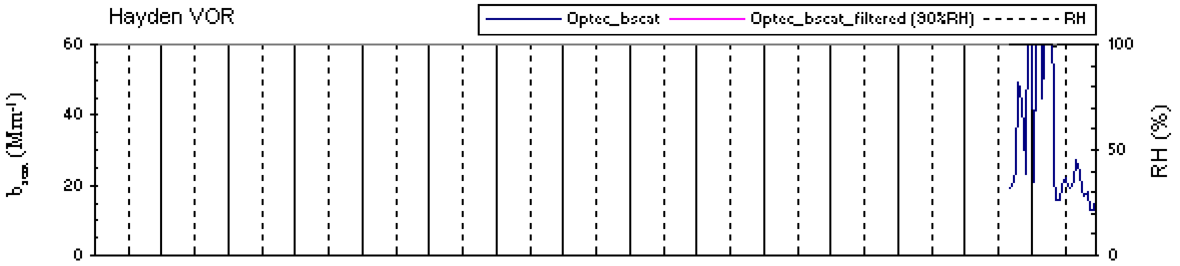
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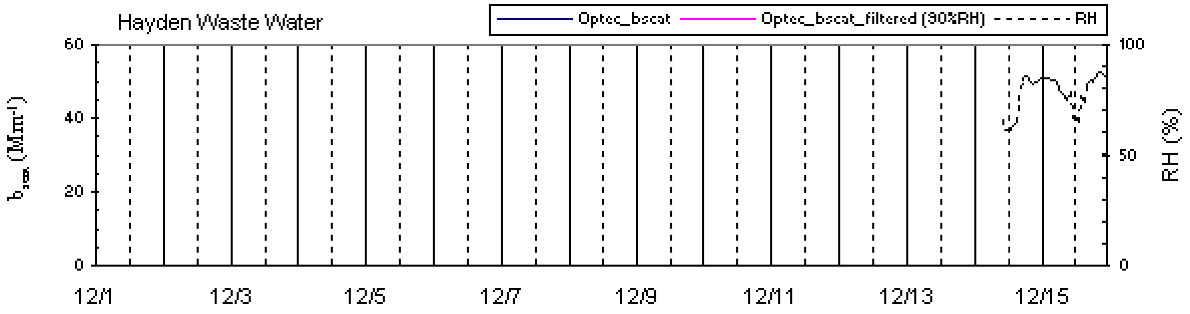
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b_scat (Mm⁻¹)
RH (%)
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12/9
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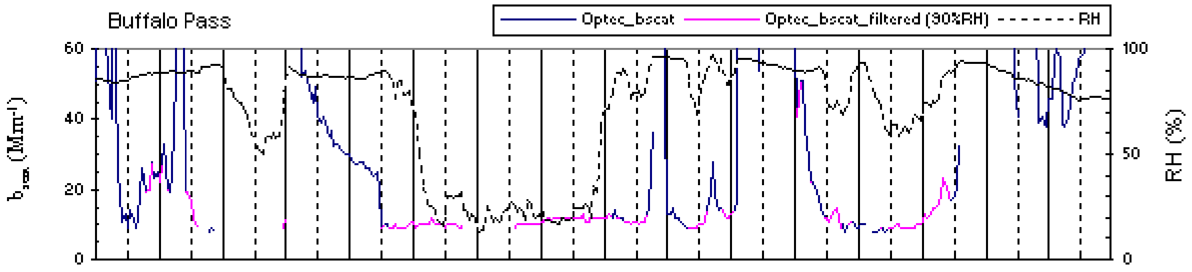
12/13
12/15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RH (%)
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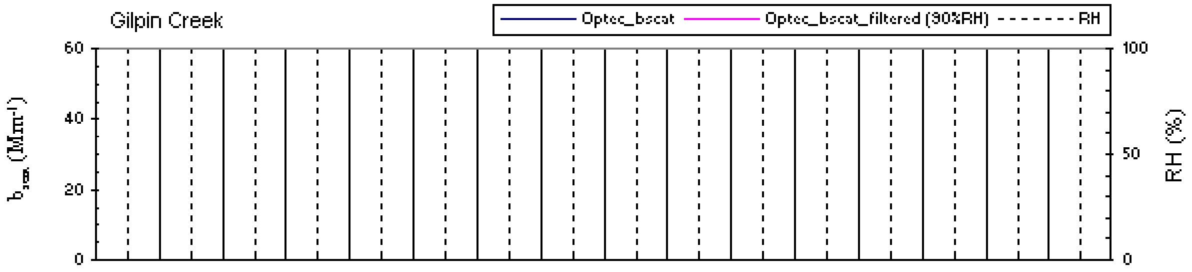
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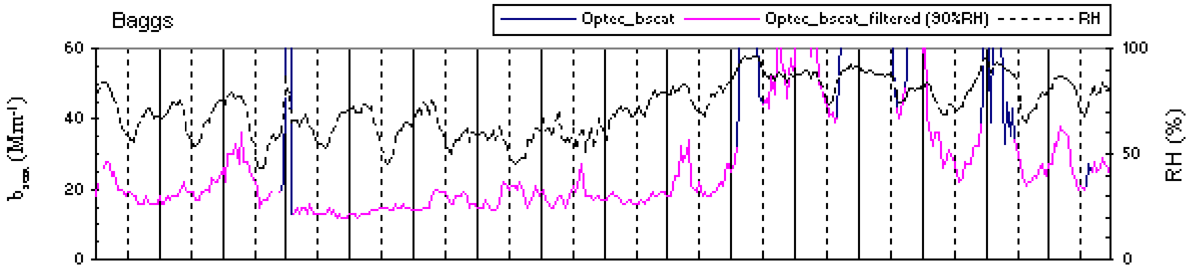
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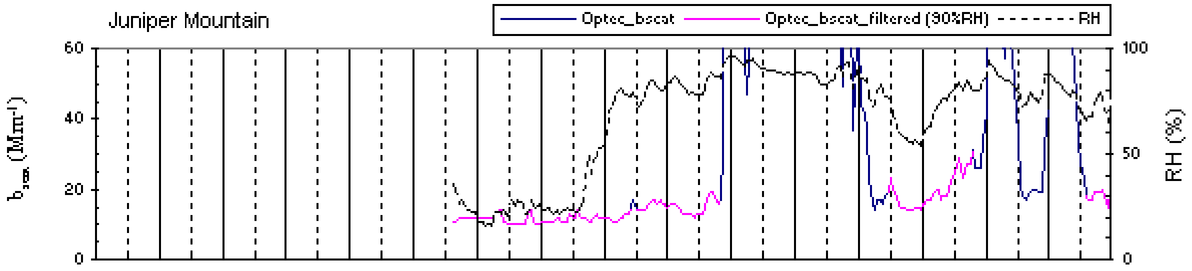
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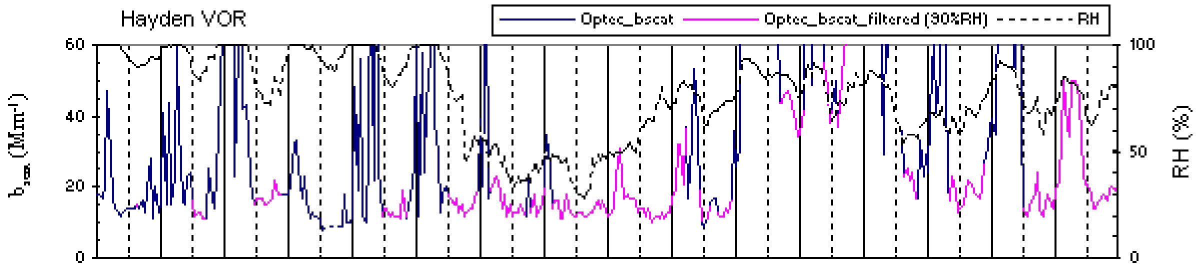
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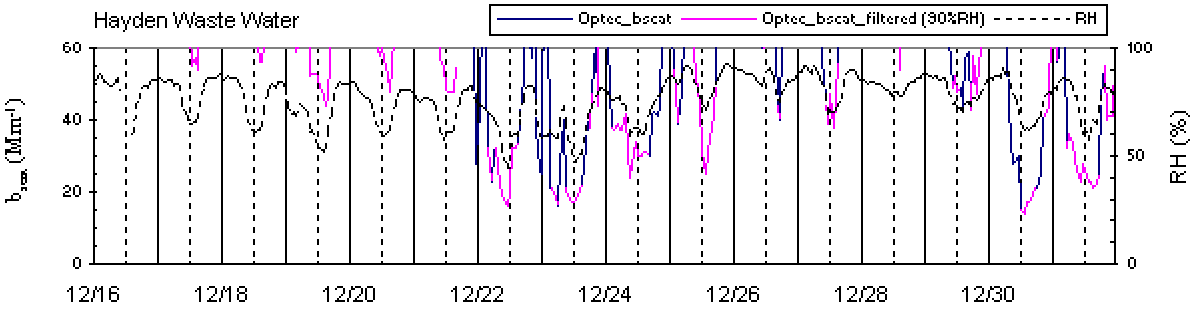
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b_{scat} (Mm^{-1})
RH (%)
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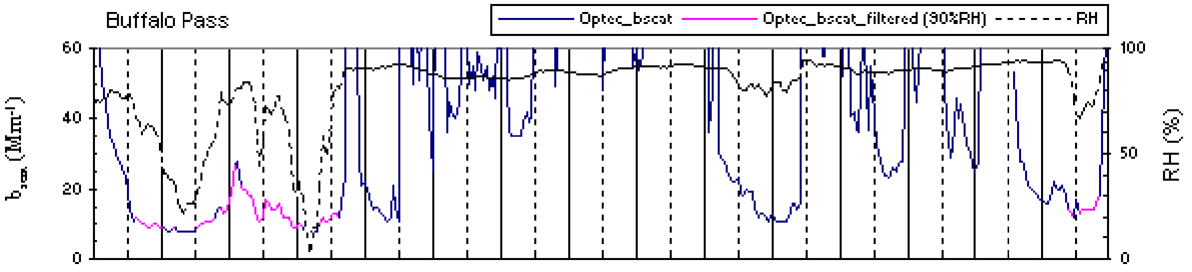
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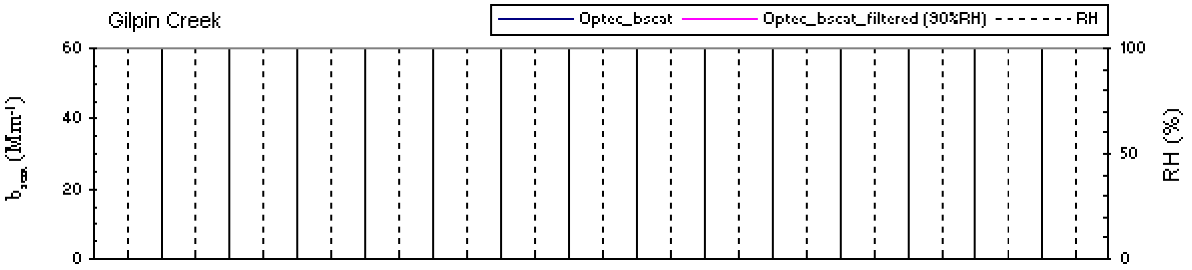
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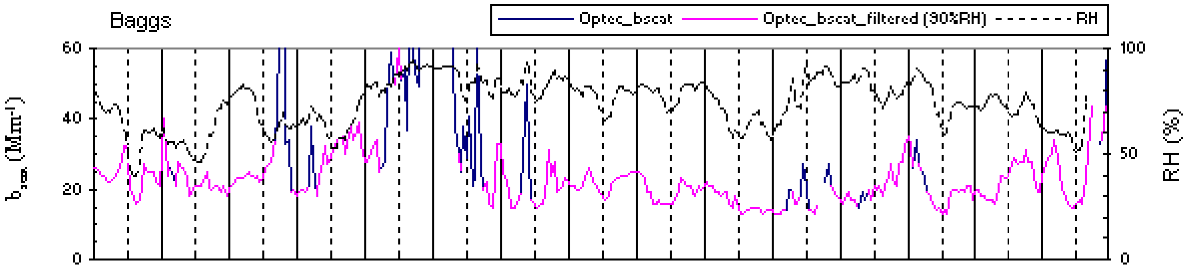
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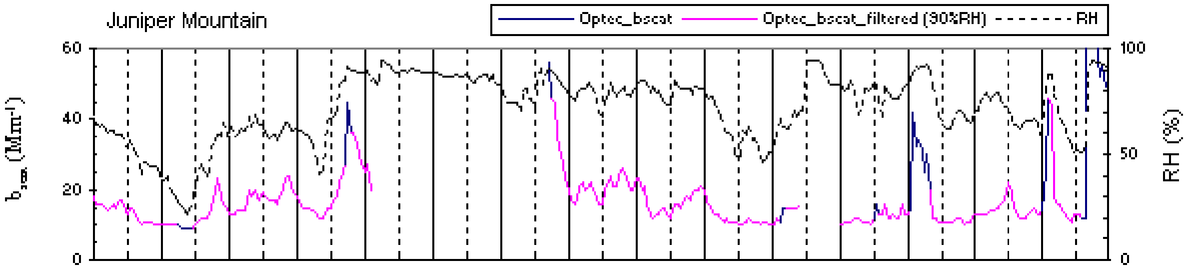
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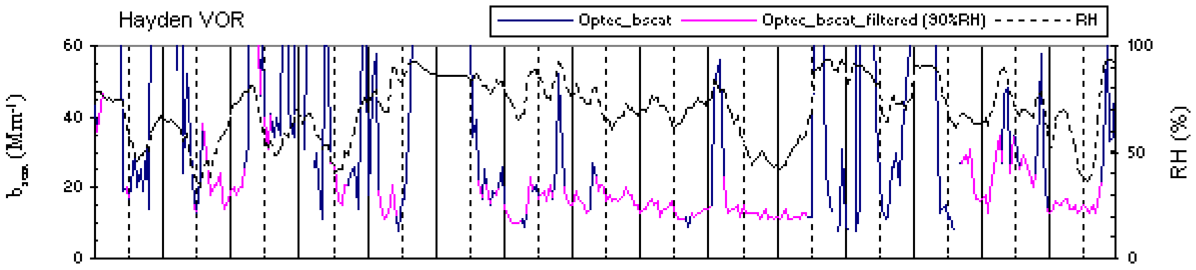
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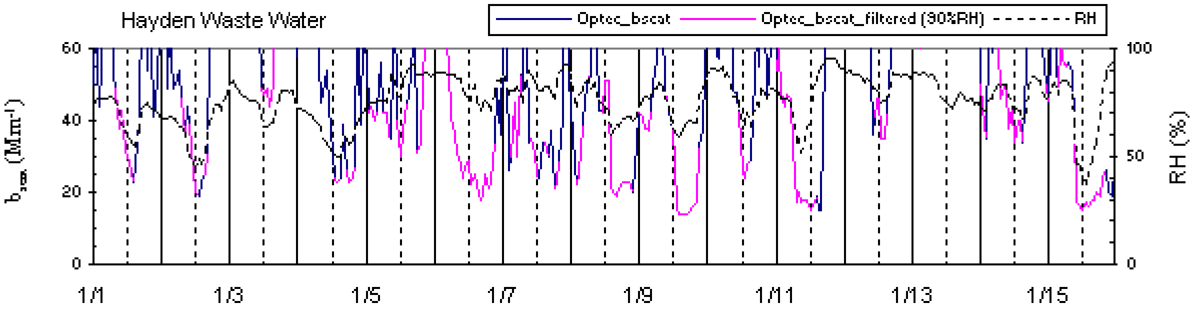
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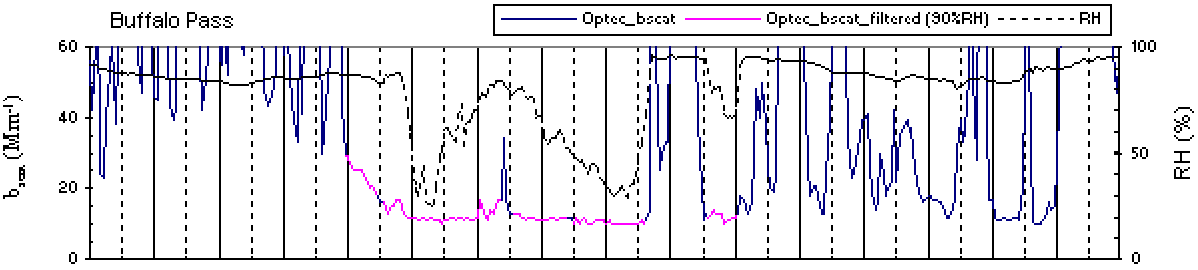
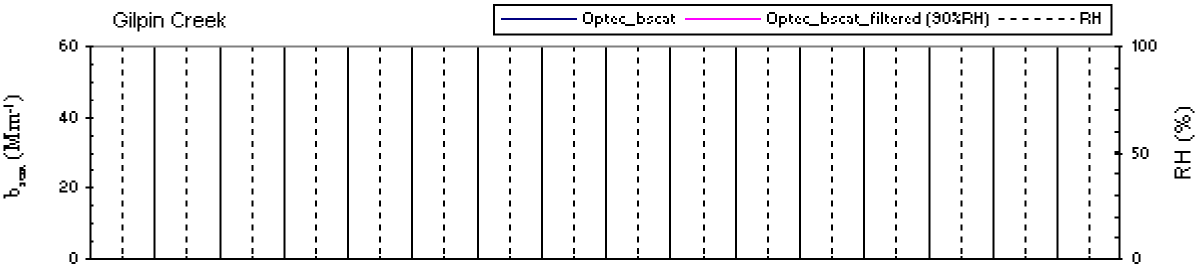
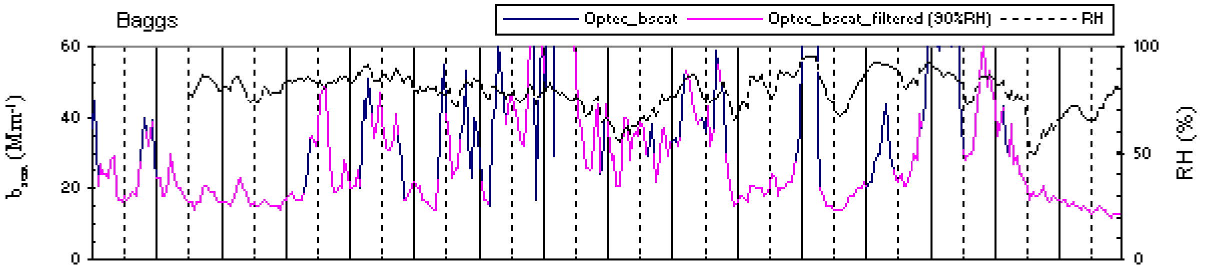
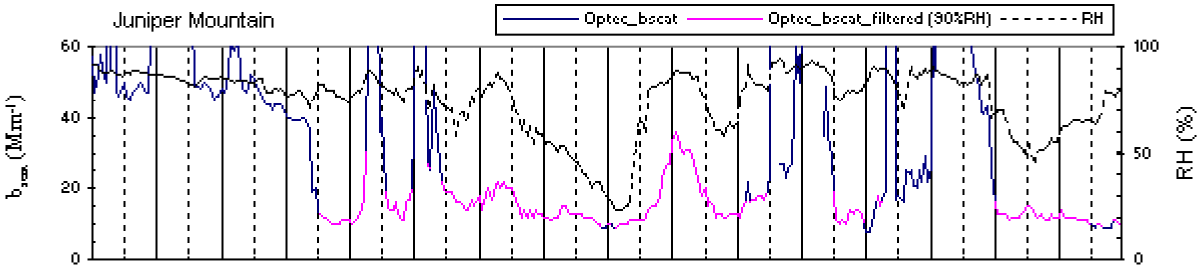
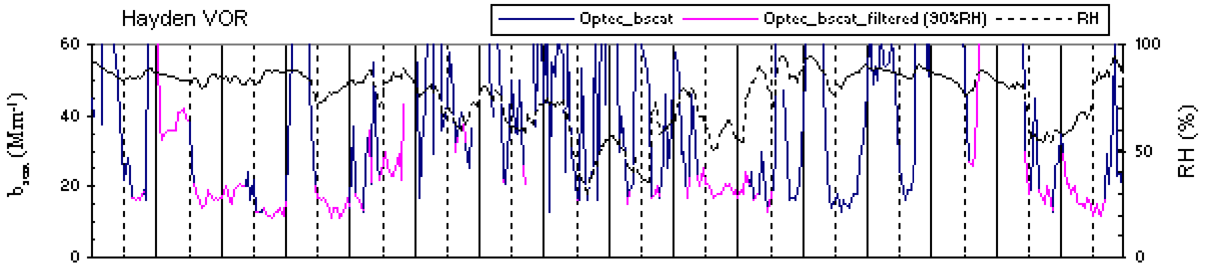
Optec_bscat_filtered (90%RH)
RH
b_scat (Mm-1)
RH (%)
0
20
40
60
0
50
100
1/1
1/3
1/5
1/7
1/9
1/11
1/13
1/15

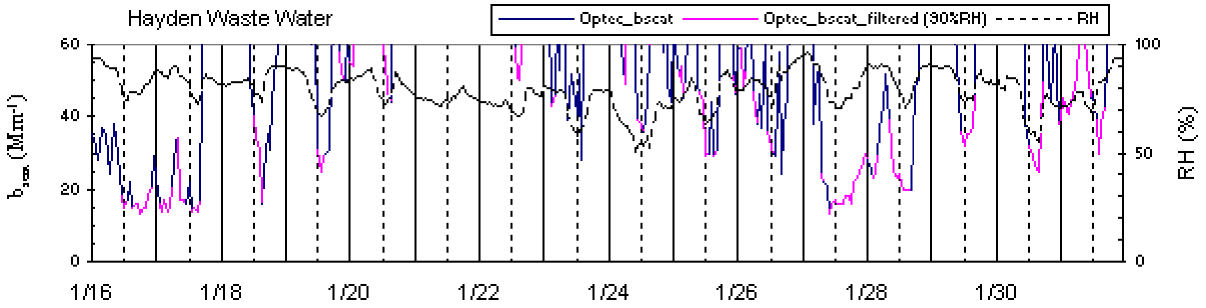

Buffalo Pass
Optec_bscat
Optec_bscat_filtered (90%RH)
RH
b_scat (Mm-1)
RH (%)
0
20
40
60
0
50
100

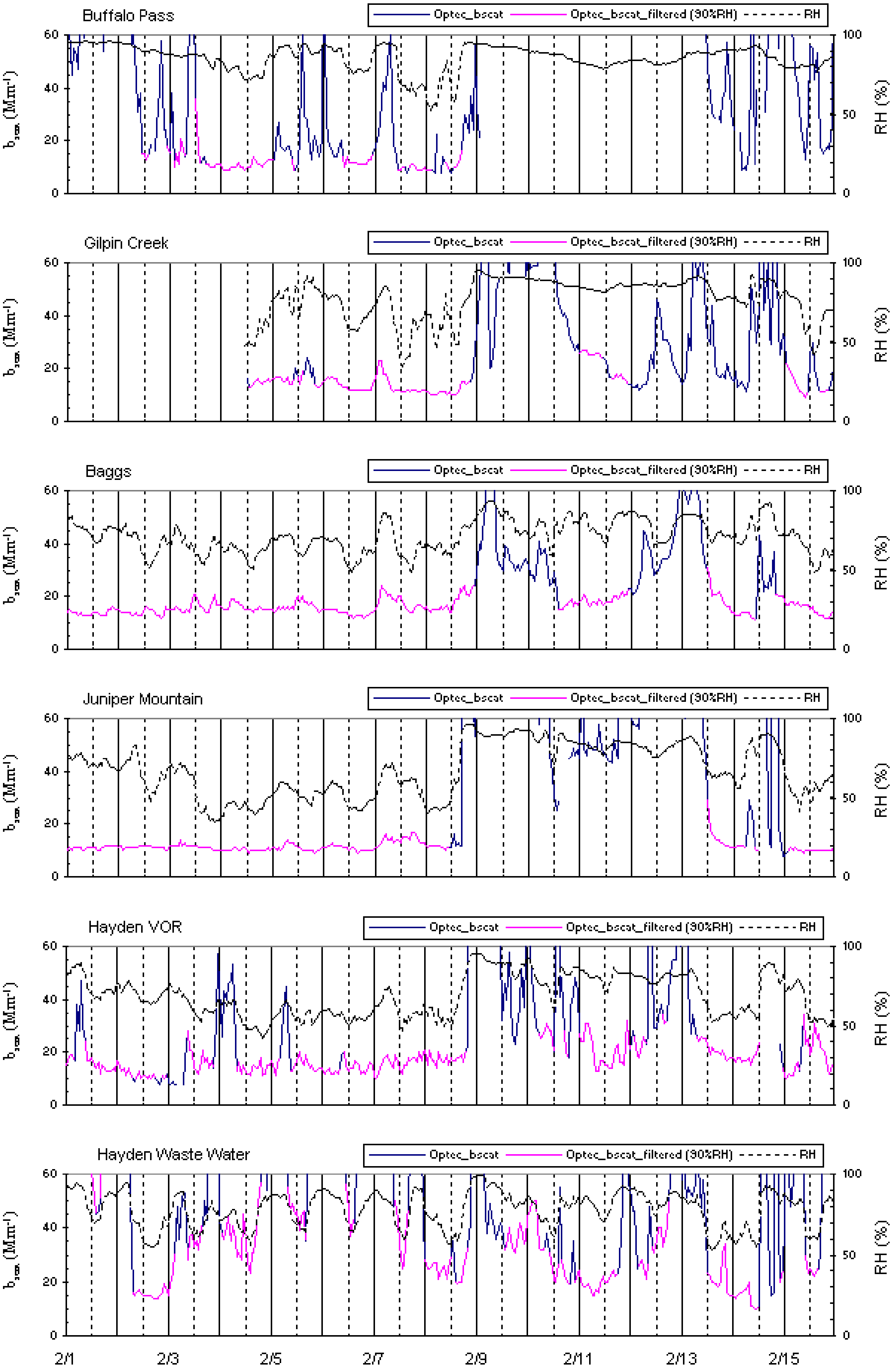

Gilpin Creek
Optec_bscat
Optec_bscat_filtered (90%RH)
RH
b_scat (Mm-1)
RH (%)
0
20
40
60
0
50
100


Baggs
Optec_bscat
Optec_bscat_filtered (90%RH)
RH
b_scat (Mm-1)
0
20
40
60
RH (%)
0
50
100

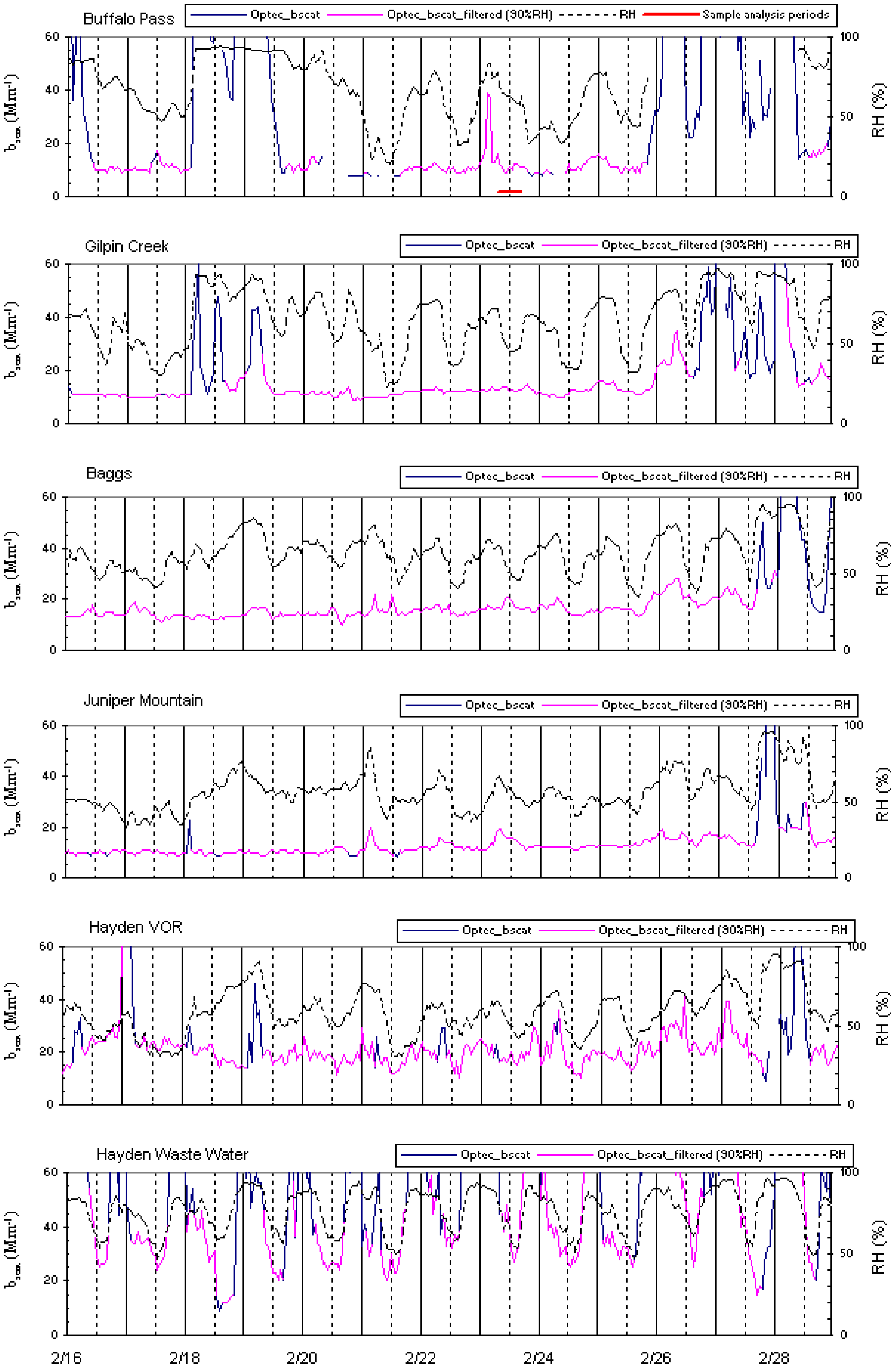

Juniper Mountain
Optec_bscat
Optec_bscat_filtered (90%RH)
RH
b_scat (Mm-1)
0
20
40
60
RH (%)
0
50
100

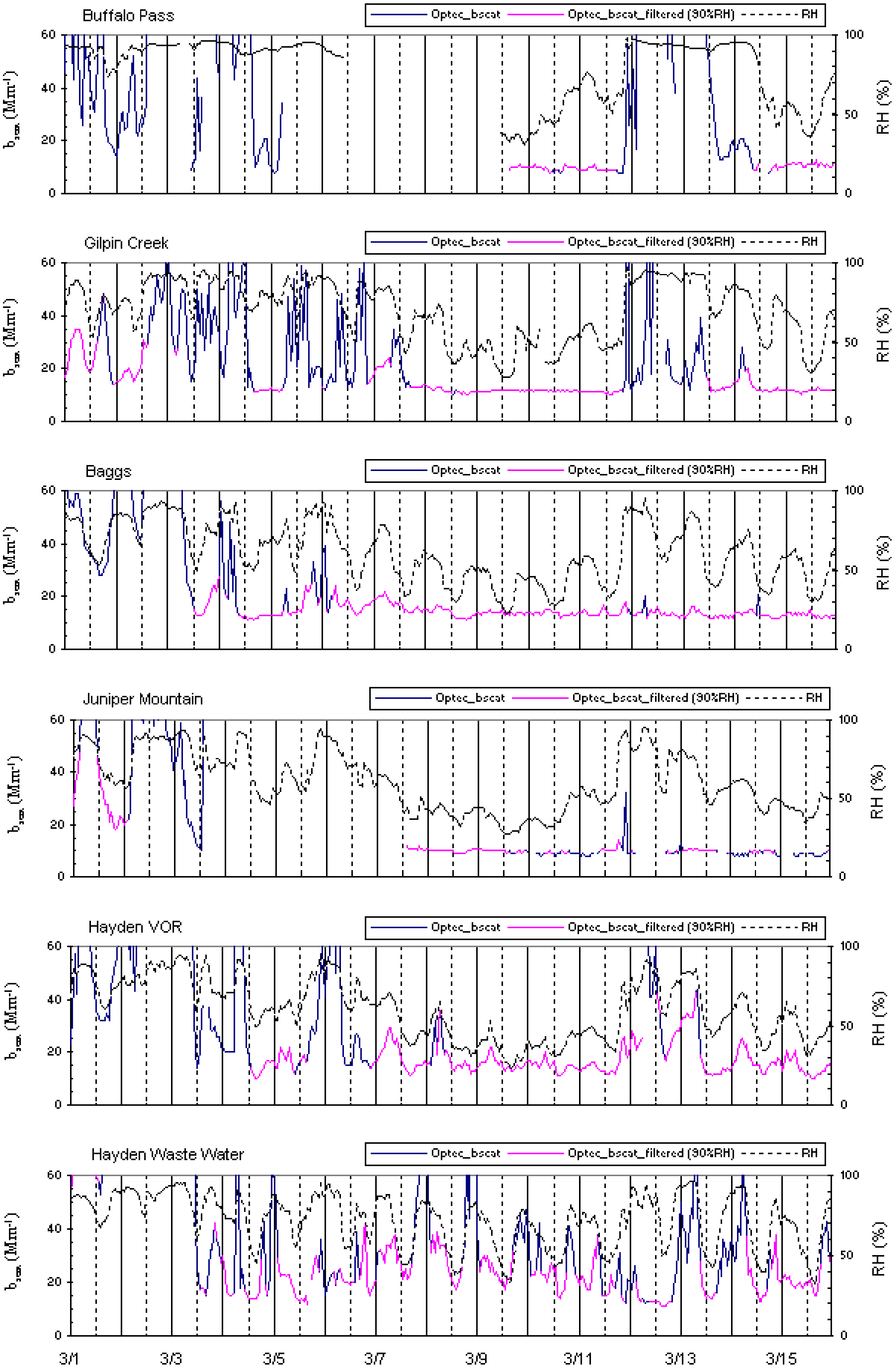

Hayden VOR
Optec_bscat
Optec_bscat_filtered (90%RH)
RH
b_scat (Mm-1)
0
20
40
60
RH (%)
0
50
100


Hayden Waste Water
Optec_bscat
Optec_bscat_filtered (90%RH)
RH
b_scat (Mm-1)
0
20
40
60
RH (%)
0
50
100
1/16
1/18
1/20
1/22
1/24
1/26
1/28
1/30



Buffalo Pass
Gilpin Creek
Baggs
Juniper Mountain
Hayden VOR
Hayden Waste Water
Optec_bscat
Optec_bscat_filtered (90%RH)
RH
b_scat (Mm⁻¹)
RH (%)
0
20
40
60
0
50
100
2/1
2/3
2/5
2/7
2/9
2/11
2/13
2/15


Buffalo Pass
Optec_bscat
Optec_bscat_filtered (90%RH)
RH
Sample analysis periods
Gilpin Creek
Baggs
Juniper Mountain
Hayden VOR
Hayden Waste Water
b_{scat} (Mm^{-1})
RH (%)
0
20
40
60
50
100
2/16
2/18
2/20
2/22
2/24
2/26
2/28


Buffalo Pass
Gilpin Creek
Baggs
Juniper Mountain
Hayden VOR
Hayden Waste Water
Optec_bscat
Optec_bscat_filtered (90%RH)
RH
b_{scat} (Mm^{-1})
RH (%)
0
20
40
60
0
50
100
3/1
3/3
3/5
3/7
3/9
3/11
3/13
3/15

3.5 Components of Light Extinction

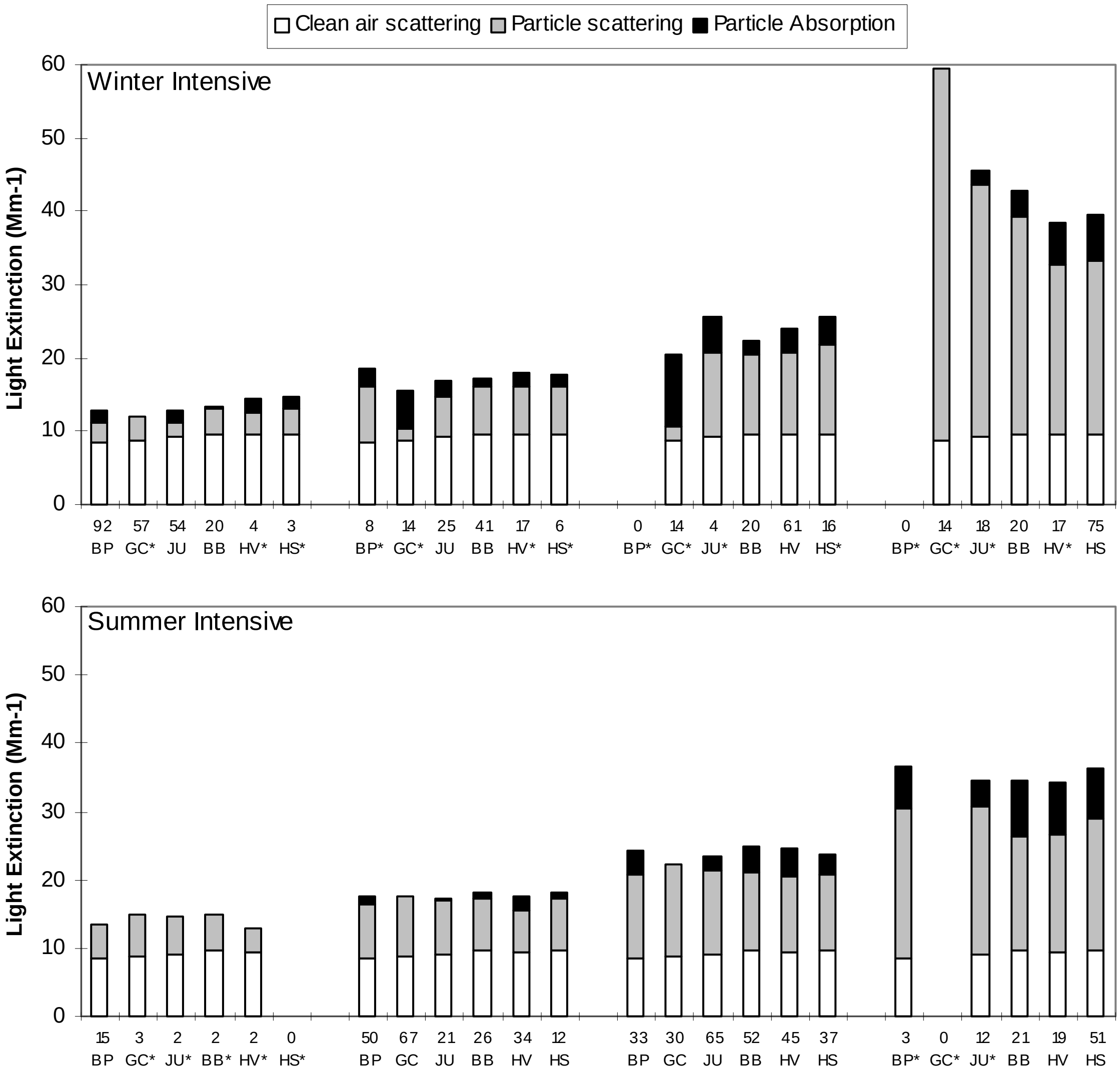
This section examines the relative contributions of clean air scattering, particle scattering, and particle absorption for different levels of light extinction. Continuous measurements of total light scattering were made at the six monitoring sites described in Section 2. Six- or twelve-hour, daytime filter measurements of light absorption were made at the same sites. The clean-air (Rayleigh) scatter contribution to light scattering was calculated for each measurement site (see the Section 3 introduction for the constant Rayleigh components for each site); and the particle scattering, Rayleigh scattering, and absorption components of light extinction were calculated for the time period of each filter sample. The variation in these components of light extinction were examined as a function of season, intensive monitoring period, location, and amount of light extinction.

Figure 3.5.1 shows the contributions to light extinction for each site for each intensive operating period (IOP). For each site and IOP, the average contributions of the above components are shown for four extinction categories: < 15 Mm^{-1}, 15-20 Mm^{-1}, 20-30 Mm^{-1}, and > 30 Mm^{-1}. Shown below each stacked bar in Figure 3.5.1 is the percentage of the total number of samples at that site for that intensive period falling into the listed extinction category. Figure 3.5.2 shows similar data averaged over seasons for the three sites that operated between intensive monitoring periods.

From Figures 3.5.1 and 3.5.2, it is clear that winter is the cleanest season at the Wilderness (Buffalo Pass and Gilpin Creek) and “background” (Baggs and Juniper Mountain) sites, while it is the haziest season at the Yampa Valley (Hayden) sites. About 90% of the valid Buffalo Pass sample periods during winter had light extinction less than 15 Mm^{-1}; while 75% of the Hayden Waste Water sample periods were above 30 Mm^{-1}. This is consistent with the strong stability in winter which traps fresh emissions in the valleys, except during storms when emissions are rapidly dispersed. From the low winter extinction levels at Buffalo Pass and Juniper Mountain, it is clear that the regional contributors to extinction are minimal in the winter. On the other hand, some of the haziest days at all sites but Buffalo Pass are in the winter, indicating the possible effects of local sources. Gilpin Creek provides an excellent example of this since it is impacted by local wood-burning in the valley below the site, as evidenced by large light scattering during the winter.

Figures 3.5.1 and 3.5.2 show the relative contributions to extinction of scattering and absorption by particles. In general, absorption accounts for less than 20% of total extinction and less than about one-third of particle extinction. However, there are a few exceptions worth noting. During the winter intensive period at Gilpin Creek, there were a few sample periods when absorption dominated the particle extinction. In addition during the non-intensive spring period from April through June at Gilpin Creek, most of the sample periods were above 30 Mm^{-1}, and the absorption dominated the particle extinction and made up almost half the total extinction. During the same period, the absorption component was high at Buffalo Pass and Juniper Mountain as well. It is likely that during both winter and spring, the Gilpin Creek site was affected by burning (either open or wood stoves) in the Elk River Valley below the site. In addition, it is likely that there were regional fires that affected most sites on some days. The fire inventory (see Section 6.2) showed a major fire of 141 km^2 to the west of the Valley during June, and numerous smaller fires up to 3 km^2 in April and May.

During the summer and fall, except for one sample at Gilpin Creek, absorption was a smaller fraction of particle and total extinction than during the winter and spring. This is consistent with the increased importance of haze due to secondary aerosols during those months. On the worst days during the summer intensive, however, the absolute amount of the absorption component at most sites was higher than during the other intensive operating periods, again indicating the importance of fires to the extinction budget.


☐ Clean air scattering ▨ Particle scattering ■ Particle Absorption
Winter Intensive
Light Extinction (Mm-1)
0
10
20
30
40
50
60
92 BP
57 GC*
54 JU
20 BB
4 HV*
3 HS*
8 BP*
14 GC*
25 JU
41 BB
17 HV*
6 HS*
0 BP*
14 GC*
4 JU*
20 BB
61 HV
16 HS*
0 BP*
14 GC*
18 JU*
20 BB
17 HV*
75 HS
Summer Intensive
Light Extinction (Mm-1)
0
10
20
30
40
50
60
15 BP
3 GC*
2 JU*
2 BB*
2 HV*
0 HS*
50 BP
67 GC
21 JU
26 BB
34 HV
12 HS
33 BP
30 GC
65 JU
52 BB
45 HV
37 HS
3 BP*
0 GC*
12 JU*
21 BB
19 HV
51 HS

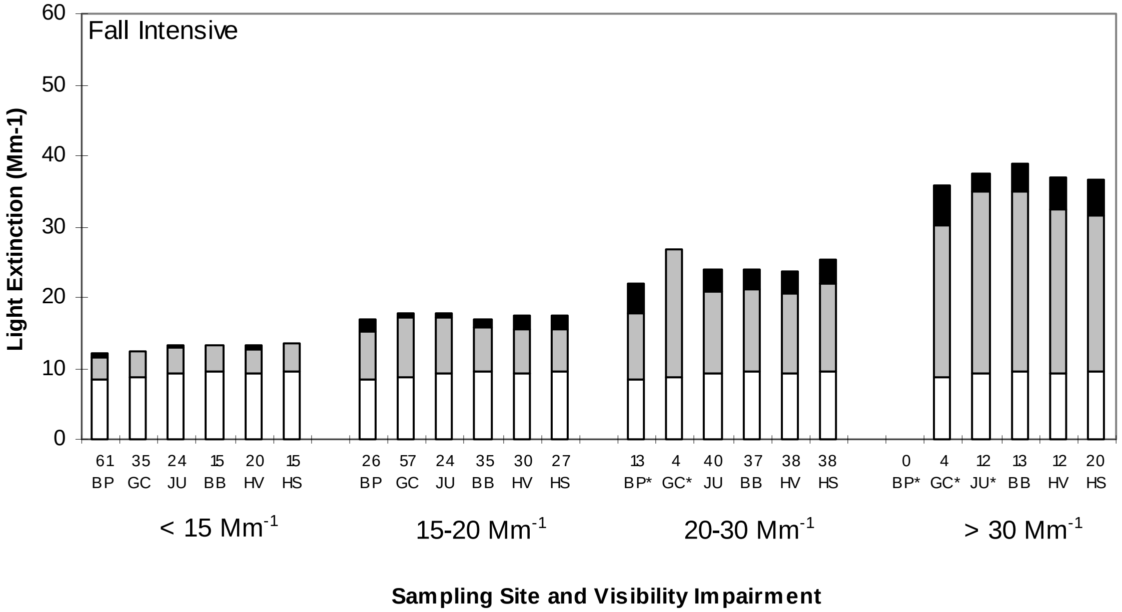
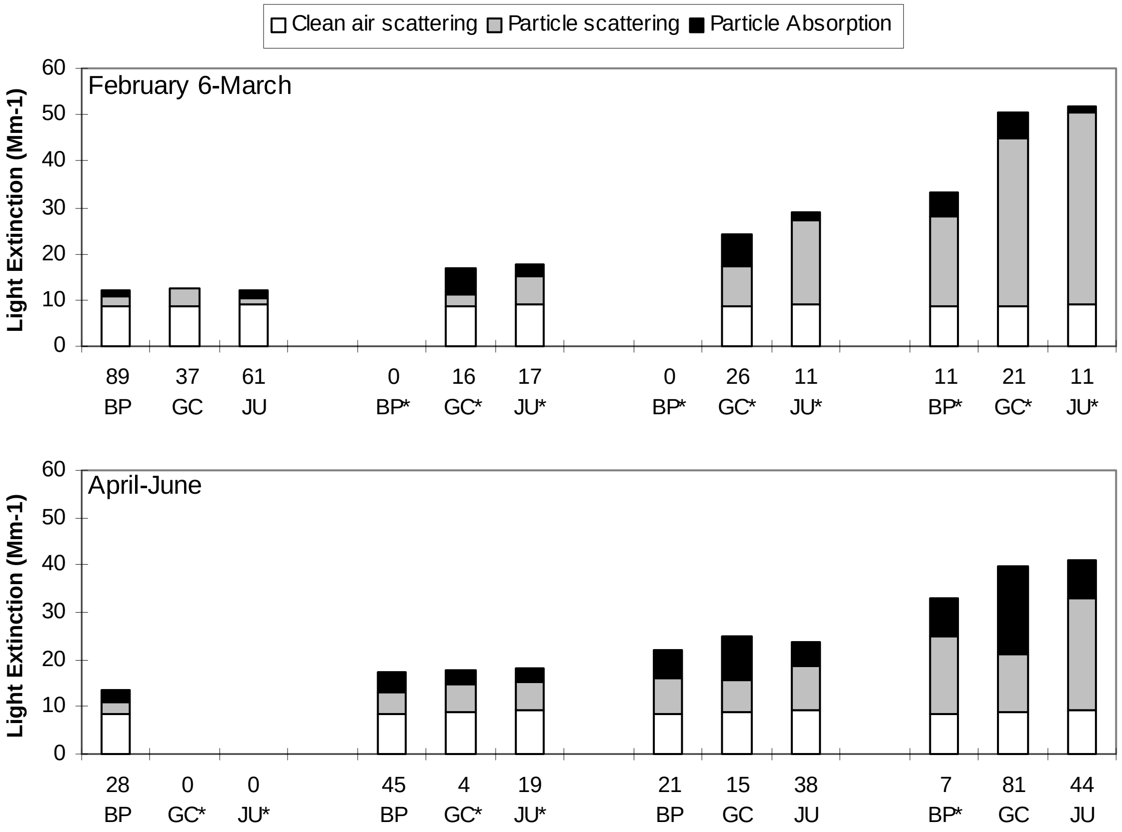


Figure 3.5.1 The components of light extinction during the intensive operating periods divided into 4 categories based on the magnitude: <15 Mm^{-1}, 15-20 Mm^{-1}, 20-30 Mm^{-1}, and >30 Mm^{-1}. The number above the site abbreviation is the percent of the valid samples during the intensive in the average. An * by the site abbreviation means there are five or fewer samples in the average.



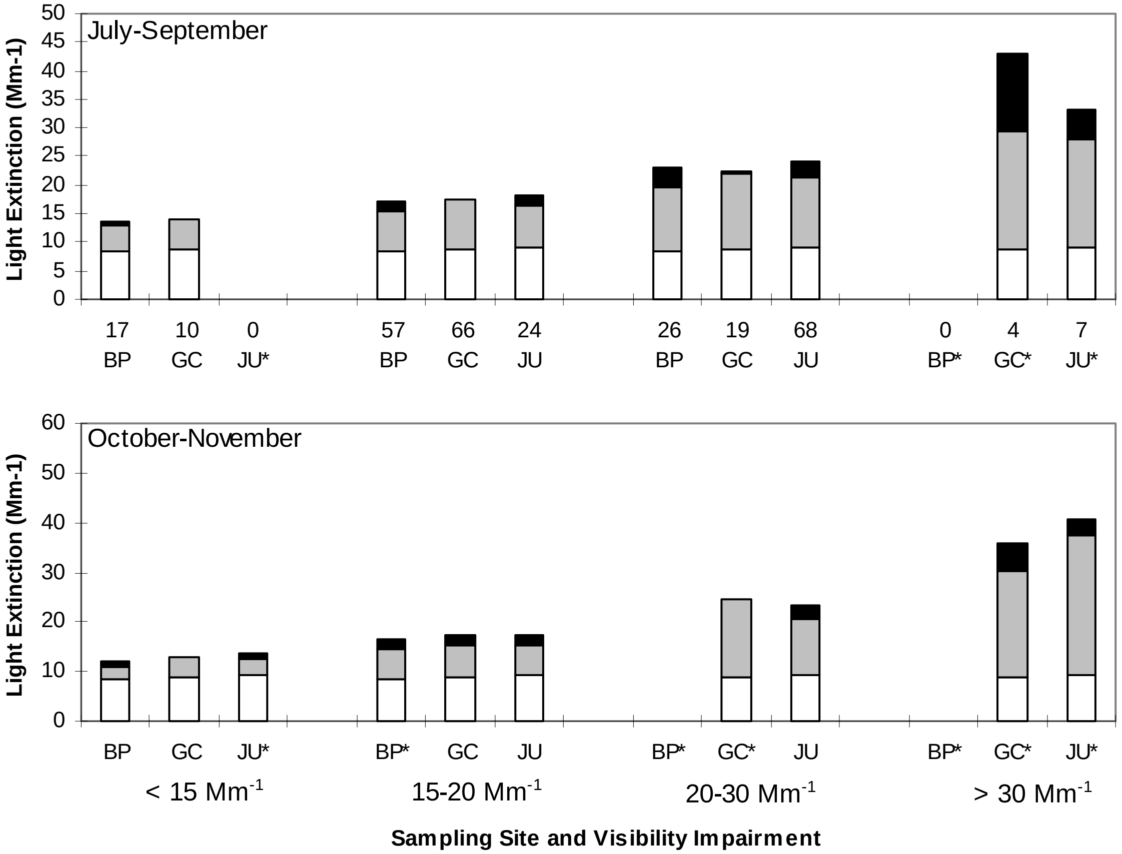


Figure 3.5.2 The components of light extinction during different seasons divided into 4 categories based on the magnitude: <15 Mm^{-1}, 15-20 Mm^{-1}, 20-30 Mm^{-1}, and >30 Mm^{-1}. The number above the site abbreviation is the percent of the valid samples during period in the average. An * by the site abbreviation means there are five or fewer samples in the average.